North Atlantic Regional
Water Resources Study

Appendix E
Flood Damage Reduction
and Water Management
for Major Rivers
and Coastal Areas

The North Atlantic Regional Water Resources (NAR) Study examined a wide variety of water and related land resources, needs and devices in formulating a broad, coordinated program to guide future resource development and management in the North Atlantic Region. The Study was authorized by the 1965 Water Resources Planning Act (PL 89-80) and the 1965 Flood Control Act (PL 89-298), and carried out under guidelines set by the Water Resources Council.
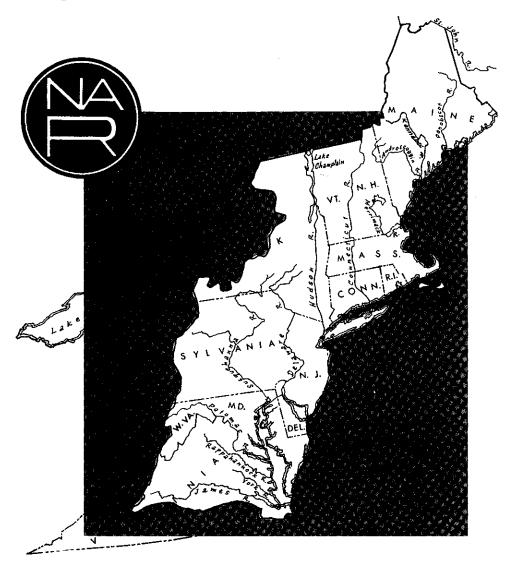
The recommended program and alternatives developed for the North Atlantic Region were prepared under the direction of the NAR Study Coordinating Committee, a partnership of resource planners representing some 25 Federal, regional and State agencies. The NAR Study Report presents this program and the alternatives as a framework for future action based on a planning period running through 2020, with bench mark planning years of 1980 and 2000.

The planning partners focused on three major objectives -- National Income, Regional Development and Environmental Quality -- in developing and documenting the information which decision-makers will need for managing water and related land resources in the interest of the people of the North Atlantic Region.

In addition to the NAR Study Main Report and Annexes, there are the following 22 Appendices:

A. History of Study
B. Economic Base
C. Climate, Meteorology and Hydrology
D. Geology and Ground Water
E. Flood Damage Reduction and Water
      Management for Major Rivers and
      Coastal Areas
F. Upstream Flood Prevention and
      Water Management
G. Land Use and Management
H. Minerals
I. Irrigation
J. Land Drainage
K. Navigation
L. Water Quality and Pollution
M. Outdoor Recreation
N. Visual and Cultural Environment
O. Fish and Wildlife
P. Power
Q. Erosion and Sedimentation
R. Water Supply
S. Legal and Institutional Environment
T. Plan Formulation
U. Coastal and Estuarine Areas
V. Health Aspects

WATER RESOURCES NEEDS AND POTENTIALS FOR AN EXPANDING SOCIETY

Appendix E
Flood Damage Reduction
and Water Management
for Major Rivers and Coastal Areas

Prepared by

North Atlantic Regional Water Resources Study Group
North Atlantic Division
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for the

NORTH ATLANTIC REGIONAL WATER RESOURCES STUDY
COORDINATING COMMITTEE

SYLLABUS

In the North Atlantic Region, there are close to one million acres of flood plain, more than one-half of which is presently developed and subject to flood damage. Because of continuing encroachment upon the flood plain, increases in the developed areas and their susceptibility to damage are anticipated. This is expected to occur in spite of increased emphasis on flood plain management, and the construction of a considerable number of flood control projects. A 1970 inventory of the Region disclosed that about 1,300 urban communities, with populations of 2,500 or more in 1960, suffered flood damages, as compared to 4,200 similar flood problem areas throughout the entire United States.

Average annual flood damages in the North Atlantic Region were about $150 million (June 1970 prices), under January 1966 conditions, and could increase to about $900 million (also June 1970 prices), by the year 2020, if no action is taken. Existing flood control structures have reduced average annual damages by approximately 40%. There is a great need to provide for the reduction of potential future flood damages in the Region, and many opportunities exist for the accomplishment of that goal. Two primary classes of flood damage reduction devices -- structural and non-structural -- are feasible to varying degrees in the North Atlantic Region. The use of both types of devices will be necessary to reduce flood damages to acceptable levels. Authorized and potential projects could reduce annual flood damages in 2020 by about 33% and together with a reduction of about 47% possible with flood plain management, could reduce damages to about $180 million.

Flood damage reduction through the year 2020 was determined by considering existing structures and structures currently believed feasible, with an increasing reliance on flood plain management in the future. Potential single-purpose structures were found desirable in highly developed areas. Also recommended are studies for multiple-purpose development of sites including flood control as a project purpose. However, in all cases, single-purpose flood control structures using storage were found to be the least desirable alternative.

By 2020, flood plain management is expected to be the dominant device for reducing damages. The magnitude of the reduction will be largely dependent upon the effectiveness of land-use controls adopted and enforced by local and State governments with the aid of Federal agencies. This turnabout from almost exclusive past use of structural measures to flood plain management dominance in 2020, will be brought about by high construction costs, decreasing locational advantages of the flood plain, and strong public opposition to most structural measures.

The water resource assumed to be presently available for withdrawal and instream uses is about 27 b.g.d. This is approximately 16%

of the average annual runoff in the Region. The potential for increas-
ing the amount of resource available for use is high. It is estimated
that it could be technically practical to increase the firm yield to
almost 72 b.g.d., or 43% of the average annual runoff, by means of
additional major river and upstream storage developments and further
ground water utilization in the Region.

While comparision of supply with projected water demands in
connection with plan formulation will undoubtedly disclose deficiencies
in certain NAR Areas and basins during the 50-year planning period,
means for redistribution of the resource, such as interbasin transfers,
are available. And the long coastline affords opportunities for
developing additional fresh water by desalting where this might be more
advantageous.

The water management information developed in this Appendix
on available resource, potential development and generalized development
costs is used in the resource input to the supply model analyses of
Appendix T, Plan Formulation.

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CHAPTER 1. INTRODUCTION

PURPOSE AND SCOPE

PURPOSE

The purpose of Appendix E is to define the magnitude of the present and projected flood threat on the main stem rivers, major tributaries and coastal areas of the North Atlantic Region; to evaluate potential programs for flood damage reduction; and to describe various aspects of, and the potential for, water management to increase the supply of water for projected future withdrawal and instream water needs. The information and data developed serve as inputs to Appendix T, Plan Formulation.

SCOPE

This Appendix includes only readily obtainable information, and no new field surveys have been made. Data on present flood damage potential, and the estimate of the extent of average annual damages, were developed from available information furnished by the Corps of Engineers' New England Division, the four Districts of the North Atlantic Division and Buffalo District, North Central Division.

Since the basic information used in developing the damage data was gathered at different times in the past, the data has been adjusted to June 1970 price levels. Adjustments have also been made to reflect known changes in the development of the flood plains. The nature of the entire investigation has been broad and unspecific. Estimates were made of the need for, and the desirability of, both structural and non-structural devices. The number and timing of the devices considered most desirable is shown.

Data presented in connection with resource development for water management were based primarily on published streamflow and similar records, and the regional yield-storage analyses from Appendix C, Climate, Meteorology and Hydrology; the ground water studies from Appendix D, Geology and Ground Water; and the upstream water management data in Appendix F, Upstream Flood Prevention and Water Management. Information on desalting was supplied by the U.S. Department of the Interior's Office of Saline Water. Estimates of potential major river storage were derived from various published reports by Federal agencies, states and others.

Appendix E does not cover flood damage to agricultural and rural community properties in upstream areas, however data on upstream water management is included. These topics are covered in detail in Appendix F.

HISTORY AND BACKGROUND

Flooding has been by far the most costly of natural disasters in the North Atlantic Region. As a product of our expanding economy and increasing demand for land, flood damages have increased so rapidly that flood protection measures hardly keep pace with the growing problem. Historically, protection measures have been used to keep flood waters away from vulnerable developments through the construction of reservoirs, levees, channel improvements and other structural devices. However, these methods are costly and best suited to highly developed areas.

Recently, the effectiveness of solely structural means of flood damage reduction has been questioned, largely as a result of the work of Dr. Gilbert White and his associates at the University of Chicago. They contend that Federal structural flood damage reduction programs encourage unwise intrusion into the flood plain because expected flood damages are underestimated or there is too much reliance on anticipated structural protection. As an alternative, they propose non-structural measures to minimize development in flood-prone areas and to achieve a more efficient allocation of resources. Emerging public concern for environmental quality has led to an increasingly broad acceptance of the non-structural approach.

Government at all levels has responded by accepting flood plain management as an equal alternative to structures for flood damage reduction. An indication of the increasing role of management is the Federal Flood Plain Management Services program, which has nearly quadrupled in the past five years. This program, which was instituted about a decade ago, aids local and State governments to control land use by zoning and other measures.

Water management for major purposes other than flood control has a long history in the North Atlantic Region starting well before the turn of the century with lake and reservoir development for log-driving and hydroelectric power in a number of rivers in New England. Storage projects designed to supply municipal needs were scattered throughout the Region around 1900. While most of these were quite small, a notable exception was Wachusett Reservoir in Massachusetts, which was completed in 1896 with a usable capacity of about 172,000 acre-feet.

Developments for power and other purposes continued in New England, mostly in Maine, in the early 1900s and larger projects began to appear in the remainder of the Region. Ashokan and Sacandaga Reservoirs in New York, Wanague Reservoir in New Jersey, Lake Wallenpaupack in Pennsylvania and the hydroelectric projects along the main stem of the Susquehanna River were in place by the early 1930s. Quabbin Reservoir, with over 1.2 million acre-feet of storage was completed in Massachusetts in 1939 by the Metropolitan District Commission.

Extensive development for New York City took place in the 1950s with the completion of Pepacton and Neversink Reservoirs in the Delaware River Basin, and Rondout Reservoir in the Hudson River Basin. This was supplemented more recently (1967) when Cannonsville Reservoir on the West Branch Delaware River became officially operational.

CHAPTER 2. METHODOLOGY AND ASSUMPTIONS

FLOOD DAMAGE REDUCTION

FLOOD DAMAGE REDUCTION FACTORS

The methodology employed developing this Appendix involves four flood damage reduction factors -- Needs, Devices, Costs, and Benefits. All data collection, analyses, and conclusions were designed to develop greater insight into these factors and their critical interrelationships.

Needs

The need for reducing flood damages is measured in terms of average annual monetary damage. Current average annual flood damages in the North Atlantic Region, under 1966 flood plain development conditions, are $146 million and are projected to increase to $889 million by the year 2020, if no action is taken to reduce damages. Damages are not projected, however, to increase at a uniform rate in all of the Region's Areas. Specific projections for each Area are included in the Regional Summary.

Devices

Devices considered in the NAR Study are broadly defined as anything done, or not done, to reduce flood damage, and are divided into two broad categories, structural and non-structural. Structural devices consist, for the purposes of this study, of storage reservoirs, local flood protection dikes and channels, and shore and hurricane protection barriers. Non-structural devices include a variety of methods of managing flood plain development.

Structural measures are by far the most familiar and well-used devices. Non-structural measures, however, at this time, are not as familiar to most people. In this study, non-structural devices are defined as any non-structural means of reducing what will subsequently be called unrestrained damages. This definition assumes that un-restrained damages would develop if no awareness of risk of loss was attached to construction or other development in the flood plain. However, since in every conceivable location some awareness of risk does exist, then in practice, some measure of flood plain management exists. That basic amount may, however, be altered upward by a variety of means, such as legislation, education, financial encouragement, flood plain zoning, regulation, flood forecasting, flood warning, flood proofing and evacuation.

Costs

The costs of flood damage reduction are defined as any associated monetary or non-monetary cost necessary to implement and maintain a device designed to reduce flood damages. Readily quantifiable investment costs are available only for structural measures; however, it is extremely difficult to establish at this time monetary costs for flood plain management. Total flood damage reduction costs are not known if non-monetary, or non-easily quantifiable costs, are to be included as a part of any analysis. Structural measures have such potential non-monetary cost aspects, such as changing the flow conditions of streams to the detriment of fish and wildlife, recreational pursuits, erosion, and sedimentation regime, as well as potential losses in landscape quality. Flood plain management measures have potential costs, such as development opportunities foregone and reduced economic growth.

Benefits

Benefits for flood damage reduction are defined as any beneficial effect resulting directly or indirectly from the devices utilized to reduce flood damages. Total benefits for flood damage reduction are as difficult to assess as total costs. It is also realized that certain hard-to-quantify benefits can occur because of flood damage reduction. Benefits, such as complementary use of storage for recreation, low-flow augmentation, visual contrast, protection of some habitat, provision of open space through non-occupance of flood plains and reduction of loss of life are known to exist, but defy precise monetary qualification.

SELECTION OF METHOD OF IMPROVEMENT

In making a selection between structural and non-structural alternatives in undeveloped areas, a determination is being made as to whether development in the flood plain is more desirable than development in areas outside the flood plain. In order for structural measures to be selected, locational advantages must exceed expected flood losses and net positive advantages in flood-prone areas must exceed those of alternative locations.

It should be noted that the derivation of future benefits by projection constitutes a potential bias toward structural measures. To the extent that past damages have resulted from imperfect information (locating in the flood plain without realizing the true expected flood losses), extrapolated future damages represent a need for information about expected flood occurrences, and not necessarily a need for flood control structures. This potential bias was a consideration in selecting between structural and non-structural flood damage reduction devices in the Area Summaries.

FLOOD DAMAGE PROJECTION

Flood damage projection is the means through which flood dam-
age reduction needs are determined.

Throughout the Study period, the first step in assessing
flood damages was the development of a method of projecting damages
under unrestrained conditions. Unrestrained conditions are those
conditions that exist when development proceeds with no awareness of
the flood plain, and excluding flood damage reduction measures. It was
felt that the best indicator of future flood damage was the future
level of damageable assets (i.e., residential, institutional, govern-
mental, commercial, industrial, and farm structures; and machinery,
inventory, and consumer goods). This assumption followed directly from
the desired form of the results; that is, the expected potential flood
damage. If potential flood damage depends, by definition, on the
amount of damageable assets, future potential flood damage can be
estimated by the predicted future levels of damageable assets under
unrestrained conditions.

As there is no reliable method of directly predicting levels
of future damageable assets, an indirect method was used. The pre-
dictions of personal income in Appendix B, Economic Base, were used to
establish a relationship between personal income and damageable assets,
thus allowing prediction of future damageable assets. Finding the
relationship of personal income to damageable assets required the use
of national data. Wealth estimates compiled by Economist Raymond Gold-
smith in his book, "National Wealth in the United States," and used by
the Office of Business Economics, provided data that was recompiled to
represent the levels of real damageable assets. The series of wealth
estimates, combined with a personal income series obtained from the
1969 Economic Report of the President, provided the necessary data.

The distributional constancy of asset growth in any par-
ticular NAR Area was implicitly assumed. If the flood plain portion
of the Area accelerates in development over the planning period, pro-
jected flood damage will fall short of actual flood damage. Alterna-
tive assumptions as to the relative growth rates of the flood plain
could have been used. However, in order to keep the NAR Study within
the realm of manageability, a neutral assumption that flood plain
damageable asset growth remains in the same relation to non-flood
plain development as in the past was made.

Damageable assets data are only available for the United
States, thus any relationship found is an aggregate one between
personal income for the United States and total damageable assets for
the United States. In order to divide the projected asset figures
between the relevant Areas, it was assumed that the ratio of damageable
assets of any Area to damageable assets in the United States, was equal
to the ratio of personal income in that Area to personal income in the

United States and that this relationship would continue throughout the planning period. Predictions of each Area's damageable asset figures were computed as follows:

$$W_{p_a} = \frac{Y_{p_a}}{Y_{p_{U.S.}}} \times W_{p_{U.S.}}$$

W = damageable assets
p = projected year
a = area, 1 ..., 21
$U.S.$ = United States
Y = personal income

Once the disaggregated predictions of damageable assets were obtained, the predicted levels of flood damage were estimated. In developing these estimates, the average annual flood damage under 1966 conditions was used to determine the portion of damageable assets that will be damaged due to floods. As was noted earlier, this proportional relationship is assumed to continue into the future. The projected flood damage was figured under the following formula:

$$D_{p_a} = \frac{W_{p_a}}{W1966_a} \times D1966_a$$

D = average annual flood damage

Once this relationship was established, a number of approaches were tried in an attempt to estimate a relationship between damageable assets and personal income that could be used to predict future asset levels. Constituent elements of the dependent variable, damageable assets, are residential, institutional, governmental, commercial, industrial and farm structures, as well as machinery, inventory, and consumer goods, so that any theoretical model has to encompass a large number of asset-holding motives. This heterogeneous variable will not yield to any of the more typical investment or consumption models, as it is a conglomerate of different variables controlled by different people for different reasons. Because of this difficulty, an obvious simplication for the model used was to fit an ordinary least squares line between current damageable assets and current personal income.

This model is as follows:

$$W_t = a + b\, Y_t + U_t$$

$$t = \text{time}$$

That is, damageable assets at time $t(W_t)$ were assumed to be a linear function of personal income at time $t(Y_t)$ and some error term (U_t).

In the search for a more rational model that has believable behavior assumptions, but is still manageable, a common quality attributable to the constituent elements of damageable assets can be found. This common element is time lags. Our dependent variable is composed of various asset variables that adjust to levels of income with varying degrees of rapidity. This adjustment speed ranges from the almost instantaneous change in consumer good holdings with changes in income levels to the highly-lagged investment reactions of public and institutional authorities.

A second model, which attempted to lag the reaction time between damageable assets and personal income, was tested and found to be inappropriate for long-term projections.

The model used was developed and tested using data for the years 1929 through 1958, as compiled by Raymond Goldsmith in "National Wealth of the United States," and shown in Table E-1. The data listed real total flood damageable assets and real personal income, adjusted for price changes. The model as used for projection, was:

$$W_t = 427 + 2.09 \ Y_t$$

The 1966 residual damages comprise the total estimated average annual damages under natural conditions, less the estimated damages prevented by presently completed projects. Constant June 1970 dollars are used throughout. Using the formulas for projected damageable assets and flood damages in each area, the projection factors given in Table E-2 were developed.

It has been concluded from the results obtained, that the percentage change in the average annual damages between the base year and any one of the target years, was about 0.7 of the corresponding percentage change in personal income; the actual factors ranged from 0.66 to 0.74.

It should be noted that the above-described projections yield upper limits for future potential average annual damages, since they are based on the assumption that the increase in reproducible tangible assets in the flood plain will be at the same rate as in the rest of the area, and no allowance was made for possible reduction of damages as a result of improved flood plain management. The degree of future damage reduction anticipated from structural measures will be covered further along in this Chapter, as will an evaluation of the extent of reduction from flood plain management which will depend upon the degree to which adequate flood warning, zoning regulations, building code provisions and other preventive measures are undertaken.

Care should be taken when using these projections. The assumptions inherent in the model and disaggregation of national data could introduce significant inconsistencies in specific localities. Projections should be recomputed whenever new assumptions are made or new data become available.

TABLE E-1
REAL TOTAL FLOOD DAMAGEABLE ASSETS
AND
REAL PERSONAL INCOME, 1929-1958

Year (t)	Real Damageable Assets (W_t)	Real Personal Income (Y_t)
1929	761	170
1930	736	156
1931	695	147
1932	702	125
1933	751	120
1934	699	128
1935	699	142
1936	744	161
1937	718	167
1938	710	156
1939	741	169
1940	768	178
1941	807	203
1942	783	232
1943	765	266
1944	754	284
1945	794	287
1946	848	270
1947	898	256
1948	892	264
1949	887	262
1950	989	284
1951	1,009	299
1952	1,031	311
1953	1,064	326
1954	1,104	326
1955	1,162	342
1956	1,199	354
1957	1,227	360
1958	1,264	361

TABLE E-2
FLOOD DAMAGE PROJECTION FACTORS
(In terms of the ratio to January 1966 damages)

AREA	1980	2000	2020
1	1.57	2.86	5.85
2	1.47	2.80	5.60
3	1.51	2.78	5.70
4	1.51	2.78	5.80
5	1.25	2.50	5.00
6	1.62	3.12	6.60
7	1.56	3.02	6.17
8	1.56	3.05	6.30
9	1.56	2.98	6.00
10	1.58	3.06	6.35
11	1.54	2.86	5.80
12	1.50	2.87	5.63
13	1.52	2.83	5.44
14	1.52	2.83	5.44
15	1.55	3.00	6.18
16	1.53	2.94	5.88
17	1.57	3.16	6.73
18	1.68	3.22	6.40
19	1.93	4.18	9.30
20	1.77	3.64	7.73
21	1.72	3.47	7.30
TOTAL NAR	1.57	3.02	6.10

The estimated natural, present and projected average annual damages for the North Atlantic Region are shown in Tables E-5 (p. E-40 and E-6 (p.E-41) in the Regional Summary.

STRUCTURAL REDUCTION POTENTIAL

Unrestrained flood damages obviously will not be sustained without some downward modification, even if only because of an awareness of the location of the flood plain. Under structural reduction potential, the effectiveness of structural devices in reducing flood damage was examined. This included an estimation of the effects and likelihood of structural measures in the future. The primary types of structures considered include beach erosion and hurricane protection works, flood control or multiple-purpose dams, and local protection channels and dikes.

Structural measures were considered in an orderly fashion. The first level was a consideration of existing, authorized, planned, or under-study projects. Second, was an evaluation of the effects of additional structures on flood damage reduction. The level of reduction possible through management was evaluated subsequently.

Existing and Studied Structures

Tables listing existing, authorized, and potential projects for each Area are included in the Area Summaries. Most of these projects have been considered as effective at some time in reducing flood damages. All projects which existed or were to be completed in 1966 were considered as effective in reducing present damages. Most authorized projects have been considered as effective beginning in 1980; however, there are exceptions in specific locations. The major criteria for considering the effectiveness of the authorized projects was developed in two steps. The first was a summation of attitudes and attributes favoring flood protection measures, which will be explained in the section of this Chapter on Flood Plain Management Reduction Potential. The second step was gathering specific details through consultation with the Corps offices having direct responsibility for project planning. The probable order of implementation and the interrelationship between project benefits was estimated. This was necessary because when many single structures are constructed, they reduce damages in reaches where additional structures may also be capable of reducing damages, and therefore, the benefits to each succeeding structure can become relatively less and less.

Structures considered as in place in future time frames are listed in Tables for each Area in the Area Summaries. Except for existing projects, costs given in these Tables are at mid-1970 price levels.

Effects of Additional Storage Structures

Considerations of the potential for additional reduction due to structural measures, was facilitated by using a system developed by the Corps of Engineers' Hydrologic Engineering Center. This system

established relationships between the reduction of average annual damages and the percentage of drainage area controlled for various amounts of storage. A discussion of the development of these relationships is contained in Appendix C. Use of the techniques derived allowed an examination of possibilities for increased storage where little specific site information existed, and was most useful in the plan formulation process when alternatives and basic data were reexamined.

The generalized relationships for evaluating the regulatory effects of potential flood damage reduction storage on average annual flood damages at downstream locations (damage centers) are shown in Figures E-1 through E-4. Instruction and guidance on the use of these relationships for estimating reductions in average annual damages follows, and Table E-3 contains examples of the computation of percent damage reduction.

When only one storage site is being considered for flood damage reduction purposes, the generalized relationships may be used directly to compute average annual damage reduction from given values of percent area controlled (% TDA), relative timing factor (RTF), and flood damage reduction storage (S). When several flood damage reduction structures are being considered, the determination of average annual damage reduction involves the computation of weighted values for percent area controlled (% $\overline{\text{TDA}}$), relative timing factor ($\overline{\text{RTF}}$), and flood damage reduction storage ($\overline{\text{S}}$). The procedure is described by the following computation steps:
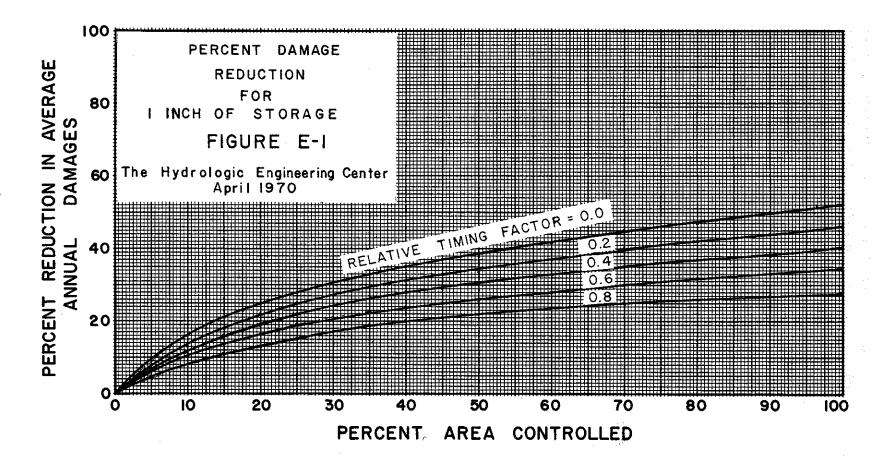
1. Determination of the total drainage area above each damage center (TDA).

2. Determination of the drainage area above each flood damage reduction structure site to be evaluated (PDA).

3. Computation of the percent of total area above each damage center that is controlled by each flood damage reduction structure site (% TDA = 100 PDA/TDA) and, if there is more than one site, compute the total percent area controlled for the n sites, as follows:
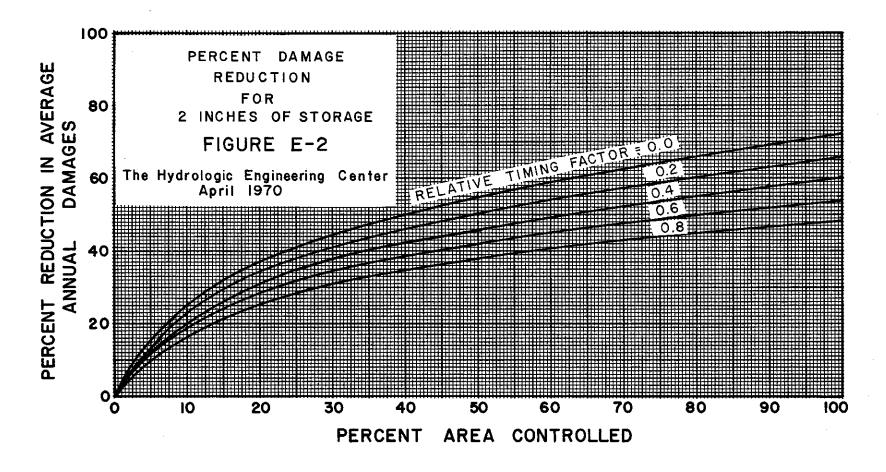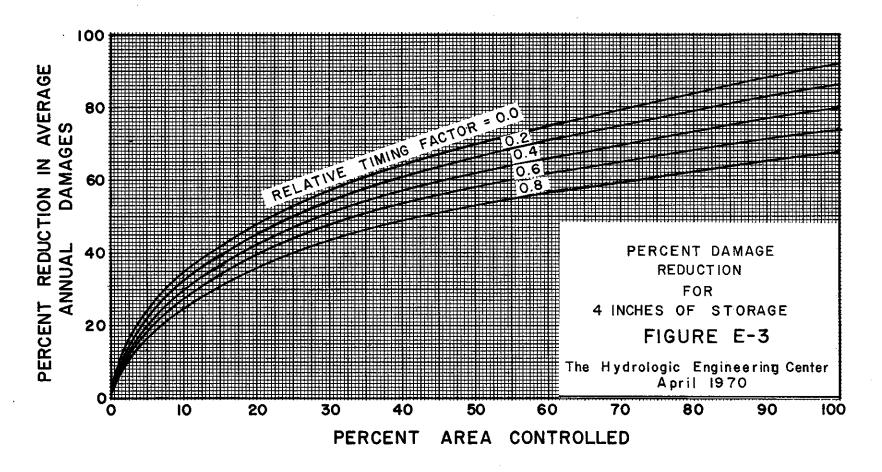
$$\% \ \overline{\text{TDA}} \ = \ \% \ \text{TDA}(1) + \% \ \text{TDA}(2) + \ldots + \% \ \text{TDA}(n).$$

4. Determination of the amount of flood damage reduction storage at each site in inches of runoff (S) and, if necessary, the weighted storage ($\overline{\text{S}}$) for the n sites by the following relation:

$$\overline{\text{S}} \ = \ \frac{\% \ \text{TDA}(1) \ S(1) + \% \ \text{TDA}(2) \ S(2) + \ldots + \% \ \text{TDA}(n) \ S(n)}{\% \ \text{TDA}(1) + \% \ \text{TDA}(2) + \ldots + \% \ \text{TDA}(n)}$$

5. Computation of the relative timing factor (RTF) for each site by the following equation:

PERCENT DAMAGE
REDUCTION
FOR
1 INCH OF STORAGE
FIGURE E-1
The Hydrologic Engineering Center
April 1970

PERCENT REDUCTION IN AVERAGE ANNUAL DAMAGES

PERCENT AREA CONTROLLED

RELATIVE TIMING FACTOR = 0.0
0.2
0.4
0.6
0.8

PERCENT DAMAGE
REDUCTION
FOR
2 INCHES OF STORAGE

FIGURE E-2

The Hydrologic Engineering Center
April 1970

RELATIVE TIMING FACTOR = 0.0
0.2
0.4
0.6
0.8

PERCENT AREA CONTROLLED

PERCENT REDUCTION IN AVERAGE ANNUAL DAMAGES

PERCENT REDUCTION IN AVERAGE ANNUAL DAMAGES

PERCENT AREA CONTROLLED

RELATIVE TIMING FACTOR = 0.0
0.2
0.4
0.6
0.8

PERCENT DAMAGE
REDUCTION
FOR
4 INCHES OF STORAGE
FIGURE E-3
The Hydrologic Engineering Center
April 1970

E-16

PERCENT REDUCTION IN AVERAGE ANNUAL DAMAGES

PERCENT AREA CONTROLLED

RELATIVE TIMING FACTOR = 0.0
0.2
0.4
0.6
0.8

PERCENT DAMAGE
REDUCTION
FOR
6 INCHES OF STORAGE
FIGURE E-4
The Hydrologic Engineering Center
April 1970

TABLE E-3
EXAMPLES OF COMPUTING PERCENT DAMAGE REDUCTION

	TDA (sq. miles)	PDA (sq. miles)	%TDA	S (inches)	RTF	% DAMAGE REDUCTION
EXAMPLE 1	1,000					
Site A		300	30	5.0	0.5	51.3

COMMENT: 51.3 = Average of 49.5 and 53.0 from graphs for 4 inches and 6 inches.

	TDA (sq. miles)	PDA (sq. miles)	%TDA	S (inches)	RTF	% DAMAGE REDUCTION
EXAMPLE 2	1,000					
Site A		300	30	5.0	0.5	
Site B		200	20	5.0	0.3	
Sum, or weighted average		500	50	5.0	0.42	63.5

COMMENT: RTF = 0.42 is weighted by equation in Step 5.

	TDA (sq. miles)	PDA (sq. miles)	%TDA	S (inches)	RTF	% DAMAGE REDUCTION
EXAMPLE 3	1,000					
Site A		300	30	5.0	0.5	
Site C		200	20	2.0	0.3	
Sum, or weighted average			50	3.8	0.46	59.0

COMMENT: Sand RFT are weighted and 59.0 is obtained by interpolation from graphs for 2 inches and 4 inches.

	TDA (sq. miles)	PDA (sq. miles)	%TDA	S (inches)	RTF	% DAMAGE REDUCTION
EXAMPLE 4						
Site A		300	30	5.0	0.5	
Site C		200	20	2.0	0.3	
Site D		200	20	4.0	0.0	
Sum, or weighted average			70	3.9	0.32	72.1

	TDA (sq. miles)	PDA (sq. miles)	%TDA	S (inches)	RTF	% DAMAGE REDUCTION
EXAMPLE 5 (In Series)	1,000					
Site A (Upstream Site)		250	–	4.0	–	
Site B (Downstream Site)		750	75	4.0	0.5	
Equivalent Storage at "B"				5.3		72.1

$$\text{Equivalent Storage} = \frac{250 \times 4 + 750 \times 4}{750} = 5.3, \text{ and}$$

COMMENT: 72.1 is obtained by interpolation from graphs for 4 inches and 6 inches.

$$RTF = \text{absolute value of the term, } 1.0 - \frac{0.6L_p + L}{0.6L_T}$$

Where:

L_T = length of the longest water course above the damage center.

L_p = length of the longest water course above the impoundment site.

L = length of the water course between the impoundment site and the damage center.

If there is more than one site, the weighted relative timing factor ($\overline{RTF}$) is computed as follows:

$$\overline{RTF} = \frac{\% \text{ TDA(1) S(1) RTF(1)} + ... + \% \text{ TDA(n) S(n) RTF(n)}}{\% \text{ TDA(1) S(1)} + ... + \% \text{ TDA(n) S(n)}}$$

6. Determination of the percent reduction in average annual damages from the appropriate Figure (Figures E-1 through E-4) using the computed percent area controlled, flood control storage, and relative timing factor. If the flood damage reduction storage or relative timing factor are not equal to one of the relations graphed, the result can be found by interpolation.

The above procedure may be used to evaluate the effectiveness of one site or multiple sites that are located on streams that are parallel. The procedure may also be used for multiple impoundment sites in series. This is true in instances where each impoundment's storage represents approximately the same degree of control over its respective local drainage area, or when storage in the downstream impoundment provides a large degree of control over the total drainage area upstream of the damage center. In these cases, the percent area controlled in the %TDA of the most downstream site, and the equivalent storage in inches is obtained by converting flood control volumes to inch-square miles and dividing by the drainage area at the most downstream site. Then, using this volume and %TDA and the RTF of the downstream site, follow the above procedure. (See Example 5, Table E-3, p. E-18.) If the degree of control in the downstream structure is small, it may be necessary to discount the storage at the downstream site because of releases, either controlled or uncontrolled, from the upstream structures.

FLOOD PLAIN MANAGEMENT REDUCTION POTENTIAL

Flood plain management reduction potential examines the use of non-structural means of meeting the need to reduce flood damages. The evaluation of structural flood damage reduction potential previously described was dependent upon the analysis of non-structural means of

flood plain management. Recognition of the interdependance of the two means required a system allowing for an examination of all factors involved in flood damage, and an assessment of the relative merits of each means.

Flood Damage Factors

The system developed to numerically compare attributes favoring either the structural or non-structural protection devices considered seven key flood damage factors. They are:

Topography. The general topography of an Area, by its steepness or flatness, determines how quickly storm waters are likely to accumulate and cause flooding. The topography thus directly influences magnitude and duration. Floods of short duration and high magnitude tend to favor protection, whereas those of longer duration and lower magnitude favor management.

Width of Flood Plain. The general width of the flood plain provides some indication of the extent to which damages will occur in the Area. For relatively wide flood plains, significant damages can be prevented with relatively modest structures, such as low levees. In relatively narrow flood plains, flood plain management is usually preferred, because of the larger or higher structural devices which would be required.

Damage Density. High concentrations of damageable assets in a flood plain generally favor structural devices, because of the high immediate return in damages prevented to existing assets. Low concentrations generally favor management devices, because of low immediate benefits and high, long-term benefits gained by preventing future assets from being located in damageable positions.

Development Stage. The development stage of cities and other asset concentrations in many ways affects the choice between management and structures. For instance, communities which are in a relatively early growth stage can generally benefit most by wise land-use planning and management to prevent the development of damageable assets in the flood plain. Cities which are already developed, on the other hand, tend to have most of their damageable assets located in the flood plain, and therefore, have the most to gain by preventing damage by structural means since it is usually too late for land-use control and management measures.

Attitude. Local or State attitudes toward any contemplated approach definitely have a major impact on its effectiveness.

Institutional Arrangement. The existing governmental and institutional arrangement can directly affect the success of either of

the two means of damage prevention. A strong government position on flood plain zoning as a management device is in many cases a pre-requisite for success. A weaker government stand, on the other hand, favors protective structures because, without adequate control on location, future damages will continue to grow to the point of justi-fying structural measures.

Visual and Cultural. Visual and aesthetic values generally tend to favor the absence of structures, since they are disruptive to the landscape. There are, however, some exceptions where the addition of water area to the landscape is desired through the construction of reservoirs.

The numerical weighting assigned to each of these factors is shown in Table E-4.

Developing the Effectiveness Factor

Data was gathered from each Corps of Engineers Office to fit the system on a stream reach by stream reach basis. Key factors were evaluated and scored individually for each reach and a reach effectiveness factor for flood plain management was developed by comparing the sum with the maximum possible score of 125. In some cases, a downward adjustment was made in the resulting factor to more realistically depict the reaches subject to less frequent flooding. Each effectiveness factor represented the percent reduction in pro-jected damages possible at a bench mark year. For example, a factor of 30% indicates that projected damages which remain at a bench mark year after reduction for previous improvements, could be reduced another 30% by flood plain management measures.

The individual stream reach effectiveness factors were used to compute a weighted basin effectiveness factor for each Area. This was done by using 1966 base condition damage figures for each stream reach to compute the amount of damage reduction attributed to a stream reach through flood plain management. These figures were then used to compute the weighted basin effectiveness factors. For example:

REACH	1966 DAMAGE	EFFECTIVENESS FACTOR	REDUCTION
A	100	.30	30
B	200	.40	80
	300		110

Weighted factor equals 110/300, or about 35%

Computed effectiveness factors were slightly modified by dis-cussion and the experience of State representatives at the third round

TABLE E-4
FLOOD PLAIN ATTRIBUTES FOR MANAGEMENT OR PROTECTION

FACTOR	MANAGEMENT	PROTECTION
TOPOGRAPHY		
Mountains	5	25
Hills	10	20
Rolling	20	10
Flatland	25	5
WIDTH OF FLOOD PLAIN		
Relatively Wide	5	10
Relatively narrow	10	5
DAMAGE DENSITY		
High	5	25
Medium	15	15
Low	25	5
DEVELOPMENT STAGE		
Early	25	5
Growing	15	15
Full Grown	5	25
Decaying	20	10
Renewing	10	20
ATTITUDE		
Favoring Management	15	5
Favoring Protection	5	15
Indecisive	10	10
INSTITUTIONAL ARRANGEMENT		
Strong Government	15	5
Medium Government	10	10
Weak Government	5	15
VISUAL AND CULTURAL		
Protection is not very disruptive	5	10
Protection is very disruptive	10	5

of plan formulation meetings. Such items as pending State legislation and potential increased impetus were considered significant.

The factor computed here represents a systematically obtained general estimate as to the effectiveness of flood plain management. The number is no better than the assumptions made and the weights assigned. In NAR Areas, flood plain management effectiveness factors in the 35% to 40% range are considered average. A range of 20% to 30% is considered low and a high rating is given to a 50% to 60% range.

DEVICES COSTS AND BENEFITS

Each device considered for reducing flood damages involves a unique combination of costs and benefits for a particular application and area..

Costs

The investment costs listed for each structural measure in the Area Summaries, as well as non-quantifiable costs in terms of effects and interactions on needs other than flood damage reduction, were evaluated. The evaluation was made in connection with the plan formulation process and involved comparisions of the relative amount of costly effects from flood damage reduction devices on the satisfaction of other needs in the Region. The evaluation system was basically a very complete objective listing of costly or harmful effects and a systematic application of uniform value judgements. It allowed a thorough review of the values involved in satisfying flood damage reduction needs, and specifically identified the trade-offs between needs.

Benefits

Benefits for structural and non-structural devices were developed in both monetary and non-monetary terms.

Monetary benefits were used at the level suggested in the latest project studies at a uniform price base. This was done realizing that benefits could increase because of increased development by the time a project was implemented. However, for those projects suggested for later implementation, it is also equally likely that redesign by that time could alter benefits to the level used. The purposes of this study did not require the up-dating of project details and benefits of implementation under future conditions. Benefits of all projects suggested for installation are, however, projected to increase in the future, at the same rate that damages would increase. (See Figure E-5, where x, and x_2 are at 1970 prices, and benefits and project details are at approximately 1970 development conditions).

Non-monetary benefits were determined as a part of the same system developed for non-monetary costs, based on identification of the beneficial interactions with other needs in the Area under consideration. The complete list of beneficial effects to other needs for satisfying flood damage reduction needs was evaluated using the same value criteria as for the cost effects.

FIGURE E-5

SAMPLE FLOOD DAMAGE REDUCTION CURVES

CURVE ABCD= Projected natural damages
CURVE AEGN = Damages modified by structures
CURVE AIKM = Damages further modified by flood plain management

X_1 = Reduction in 1980 for structures built in 1980
X_1' = Reduction in 2000 for structures built in 1980
X_2 = Reduction in 2000 for structures built in 2000
X_3 = Reduction in 2020 due to all previously built structures
X_4 = Reduction in 2020 for structures built in 2020

Y_1 = Reduction in 1980 for FPM in 1980
Y_1' = Reduction in 2000 for 1980 FPM
Y_2 = Reduction in 2000 for FPM in 2000
Y_3 = Reduction in 2020 for all previous FPM
Y_4 = Reduction in 2020 for 2020 FPM

C/B x E = F   D/C x G = H
G/E x I = J   N/G x K = L
$J - Y_2 = K$ $L - Y_4 = M$

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All information on costs and benefits was then used in the
plan formulation process, so that conclusions could be made about the
best combinations of devices to meet each Area's planning objectives.

PLANNING OBJECTIVES

An examination was made of potential differences between the
emphasized planning objectives for all Areas. In general, the major
differences existing between objectives for flood damage reduction
will be exhibited most strongly under a strict Environmental Quality
objective. The device most suitable for an Environmental Quality
objective is often increased reliance on flood plain management mea-
sures.

Strict Regional Development and National Income objec-
tives generally rely more on structural means of flood damage reduc-
tion, with the object of relieving existing damages as early as possi-
ble and supplementing the structures only to a degree readily attain-
able with flood plain management.

In most Areas of the North Atlantic Region, however, it was
not possible to clearly differentiate between planning objectives.
Since, in many cases, some structures were considered necessary and
desirable for implementation under all objectives, it became relatively
immaterial whether amounts of structures and distribution could be
shifted upward or downward slightly for each different objective. In
fact, because of the fixed location of damage centers, and resulting
locational constraints on feasible sites, changes between objectives
did not present viable structural alternatives. Consideration was
given to varying the degree of effectiveness of flood plain management
between objectives, wherever possible. In many cases, however, the
potential difference was not discernable in the estimation of the
effectiveness factor.

During the third round of plan formulation, particular atten-
tion was given to a thorough consideration of the potential differences
between planning objectives. It was found that differences existed in
only seven of the 21 planning Areas.

In Areas 4, 8, 9, 14, 19 and 21, programs for the National
Efficiency and Regional Development objectives were the same, while the
Environmental Quality objective was different. In Area 17, programs
for the National Income and Enviornmental Quality Objectives were
the same, differing from the Regional Development Objective.

In all cases, the planning objective group which included
Environmental Quality needed fewer structural measures than the group
including National Income. More specific details are presented in
Chapter 4, Area Summaries.

WATER MANAGEMENT

Management of the water resource to satisfy withdrawal and instream needs in many Areas of the Region depends to a large extent on structural measures to store surface runoff and develop ground water so as to assure dependable supplies during low flow seasons. The more critical areas, generally those with the larger concentrations of population, utilize extensive interbasin diversion systems to bring the stored water to the areas of need. As demands grow during the planning period, greater development of the resource is inevitable. Fortunately, as pointed out in Appendix C and Appendix D, a large regional resource is available for future development.

DEVELOPMENT POTENTIAL

For the purpose of comparing the water resources of the 21 NAR Areas with prospective needs and with each other, an estimate was made of a potential upper limit to development in each area. This has been termed the "practical development" limit and is based on hypothetical development by means of major river and upstream storage and by ground water. The limit is arbitrary, based on judgement as to the degree of development that would be possible in an Area without incurring inordinately high costs, monetary or other, and assumes that the criteria for determining the yield of the various types of development give similar results that may be combined. The practical development limits are guide values, derived in a consistent manner for all Areas, that may be compared with needs for an indication of the Areas in which future water management problems may become particularly acute as well as the Areas with the more abundant supplies. The methodology for the formulation of practical development limits as outlined in the following paragraphs is not meant to imply any degree of inevitability to particular sources of development nor to the total development within an Area.

MAJOR RIVER STORAGE

The determination of major river storage potential in each Area was based on information from other studies on sites which had been investigated. The NENYIAC Study of New York and New England; basin studies for the Connecticut, Delaware, Susquehanna, Potomac, Rappahannock, and James Rivers; the Northeastern United States Water Supply Study, and various state studies, were all utilized in the collection of data on potential storage reservoir projects. In each Area, a list of storage possibilities was made by screening all sites and selecting those that appeared to involve the highest degree of feasibility, assuming, hypothetically, a firm need for the stored water. The determination of which storage projects to include was largely a matter of judgment, influenced by the results of previous studies, as well as by information received in the NAR Study.The level of development at each site was comparable to that previously studied except for a few cases where some reduction was made to allow for the

possible addition of flood control storage. While the criteria of
storage selection would lean toward emphasis of the National Efficiency
objective, it is believed that the assumed development limit would
equal or exceed amounts that might be considered within an area under
programs exphasizing any of the three planning objectives. Practical
development storage potential for major rivers is summarized in Table
E-8 (p.E-47) in the Regional Summary.

Yield which would result from major river storage was deter-
mined by means of the yield-storage relationships developed on a "per
square mile" basis for synthetically generated streamflows in Appendix
C. In most cases, the yield for each potential project was determined
at the site from the closest relationship available in the Appendix C
data and all project yields were summed to arrive at the total gross
yield for an area. Net yield was calculated by subtracting the minimum
(approximately 7 day - 50 year) flow which would occur in the absence
of the projects. (See the analysis of minimum flows in Appendix C.)
In a few instances, where it could be anticipated that the need for
water would be predominantly at a downstream location, a yield-storage
relationship for this downstream point was used. In both cases, yields
were based on a shortage index of 0.01. Shortage index is a risk
criteria that combines frequency of shortage with magnitude of shortage
and is defined as the sum of the squares of the annual shortage over a
100-year period, where each shortage is expressed as a ratio to the
annual requirement. An index of 0.01 would be equivalent to various
combinations of shortage in 100 years, such as one 10% shortage, two 7%
shortages, or one 7% and three 4% shortages.
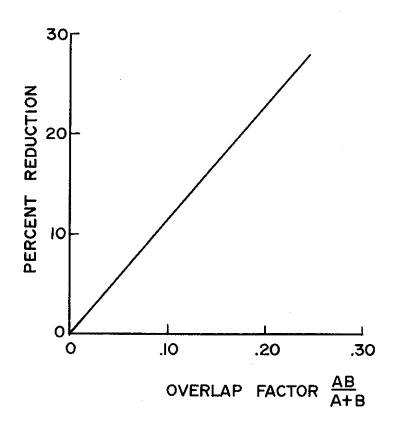
UPSTREAM STORAGE

The beneficial storage other than flood control in potential
upstream reservoirs was evaluated by the Department of Agriculture.
This storage was derived from watershed inventories and is the maximum
practical development based on yield, topography, and rights of way. A
summary of upstream storage and yield potential is presented in Table
E-9 (p.E-48) in the Regional Summary. Additional information is contained
in Appendix F. A discussion of the analysis of gross yield from upstream
storage is included in Appendix C. This yield is based on criteria of 1%
chance of shortage or deficient flow. It was assumed that it would not
be practical to operate potential upstream reservoirs for points located
substantial distances downstream, and yields were determined at each site.
Minimum flows based on the drainage area controlled were subtracted to
develop the net yield to be expected from the potential projects.

ADJUSTMENT FOR OVERLAP IN STORAGE DEVELOPMENT

To account for duplication of yield due to possible overlap
in drainage area controlled by major river and upstream storage at the
practical development limit, a general relationship for estimating re-
duction in total yield was assumed. This relationship (Figure E-6),

FIGURE E-6

REDUCTION IN YIELD DUE TO OVERLAP
BETWEEN UPSTREAM AND MAJOR RIVER STORAGE

relates percent reduction in total yield to a factor reflecting the probability of overlap in an area. The calculated factor is:

$$\frac{AB}{A+B} \quad \text{where}$$

$$A = \frac{\text{total net yield from potential upstream storage}}{\text{average annual flow} - \text{existing minimum flow}}$$

and

$$B = \frac{\text{total net yield from potential major river storage}}{\text{average annual flow} - \text{existing minimum flow}}$$

No detailed analysis was made to develop the reduction relationship. Since the values of A and B would approach 1 as development increased, the reduction factor would tend to approach 0.5 for near complete overlap of development. It was assumed that the reduction should be on the order of 50% at this point. Results appear consistent and reasonable throughout a range of situations. The effect of any existing development is recognized by incorporating existing minimum flow in the equations for A and B.

Overlap reductions were calculated for each of the 50 Sub-areas used for supply model analysis and varied up to a maximum of about 24%. The average reduction was approximately 5%. Sub-area data were combined and the results summarized for the 21 NAR Areas in Table E-10 (p.E-49) in the Regional Summary. It is noted that reductions range up to about 15% for the 21 Areas in this Table.

GROUND WATER

Estimates of the practical development yield of ground water are presented in Appendix D. These data represent conservative estimates of maximum withdrawal rates that could be sustained as determined by the hydrologic and geologic characteristics of the aquifers. Separate information is included for coastal plain strata, consolidated rocks and glacial deposits. Data are sub-divided according to prospective use as indicated by the nature and location of resource into the higher yield wells for municipal and industrial water, and the smaller developments suitable for rural and irrigation water. The latter would consist mainly of wells in crystalline and metamorphic rocks generally yielding less than 100 g.p.m.

As pointed out in Appendix D, total yield cannot be assumed to be the sum of the yields from prospective ground and surface development. Ground water and surface water are part of the same hydrologic system and withdrawal from one can significantly reduce the yield of the other. For example, since ground water outflow is a significant part of streamflow, particularly during low flow periods, pumping of wells may simply capture part of the ground water outflow to the

streams or, if the wells are near the streams, may induce infiltration of water directly from the streams. While the use of ground water under such circumstances might well be preferable to the use of surface water in some cases, little or no gain in overall available resource would result.

In order to integrate the additional resource available through ground water utilization into the total practical development limit previously defined, several arbitrary assumptions were made with regard to the complex relationship between surface and ground water. Since the larger industries and cities are generally located on or near the larger streams, it was assumed that allowances should be made for subtractive effects on streamflow when incorporating the municipal and industrial ground water. On the other hand, since most of the rural and irrigation ground water occurs at some distance from major streams and in consolidated rocks, it was assumed that the time lags would be such that no appreciable subtractive effects would occur during low flow periods.

The subtractive effects of developing municipal and industrial water were accounted for by the use of appropriate generalized factors expressing the percentage of the total water that was assumed to be additive to the resource in each of the various types of aquifers. These factors were adopted on the basis of the judgement of Geological Survey and Corps of Engineers personnel developing this data and are averages estimated for the Region as a whole. In actuality, considerable variation between basins with similar aquifers would be possible. Also, the factors are based on an assumed critical period of 90 days. While this is longer than the critical period in which minimum streamflows are based in this Study, only moderate fluctuations are observed in many rivers for several months during low flow years. Certainly, under the more regulated conditions with which the practical development analysis is concerned, with a resultant smoothing of flows, critical periods of up to 90 days do not seem unreasonable.

For the glacial deposits, which occur mostly in close proximity to streams, and have high permability and good hydraulic connection, it was assumed that only about 5% of the pumped water would represent water from storage rather than the stream, and thus additive. Wells in the consolidated rocks would be more widely distributed rather than concentrated near large rivers and streams and would draw on storage to a greater extent during low flow months. The additive portion of pumped water was assumed to be 20% in this case. For coastal plain formations, practically all (95%) of the development was considered additive in the case of artesian aquifers while in the shallow surficial deposits, none of the yield was assumed to be additive to the overall resource.

In accordance with the type of water-bearing deposits in each of the 50 NAR Sub-areas, a composite percentage factor was developed to

account for the additive portion of the municipal and industrial ground water. For example, in Sub-area 10b, about 29% of the water is in consolidated rock and 71% in glacial deposits. The composite factor would then be 29(.20) + 71(.05), or 9%. Information developed on a Sub-area basis was combined into the 21 Areas for presentation in Table E-11 (p.E-50) in the Regional Summary.

DEVELOPMENT COSTS

Generalized analyses of the costs of major river storage, water transfer and desalting were made for use in the NAR Supply Model analysis for withdrawal and instream needs. These complement cost studies for upstream water management development made in connection with Appendix F, and for ground water as covered in Appendix D.

Major River Storage Costs

The costs of storage relationships for major river storage in the six Sub-regions were derived through collection and analysis of data on studied and completed reservoir projects throughout the North Atlantic Region by the New England Division, Corps of Engineers.

Reservoir cost information was compiled through Corps Offices from project studies, annual reports, basin study reports and other sources. Data were collected on just over 1,000 separate storage projects, of which 46 had been actually constructed. Most of the projects involved were Federal undertakings; however, some 300 were from private and state studies.

The majority of dams consisted of earth and rock fill embankments with ungated spillways, gated intake structures and outlet tunnels or conduits. Project cost was considered as total cost including dam and appartenances, lands and damages, relocations, reservoir, fish and wildlife mitigation lands, general recreation facilities, buildings, grounds and utilities, beautification and permanent operating equipment. All costs included engineering, design, supervision and administration and were adjusted to 1967 price levels for the regression analyses. The results of the analyses were subsequently adjusted to 1970 price levels. Storage was considered to be total storage including dead storage (sediment and inactive), conservation or power storage, flood control storage and controllable surcharge (crest gates on top included).

Regression equations computed through statistical analyses of the data for the six NAR Sub-regions are listed below. Dummy variable analysis and the F-test were used to confirm that the Sub-regional differences were significant.

SUB-REGION	EQUATION
A	$C = 13.1097 + 0.0217S$
B	$C = 3.2426 + 0.1462S$
C	$C = 12.5512 + 0.1444S$
D	$C = 17.2329 + 0.1644S$
E	$C = 2.9034 + 0.1781S$
F	$C = 13.4452 + 0.0601S$

Where C = cost in millions of dollars (1967)
and S = storage in 1,000 acre-feet.
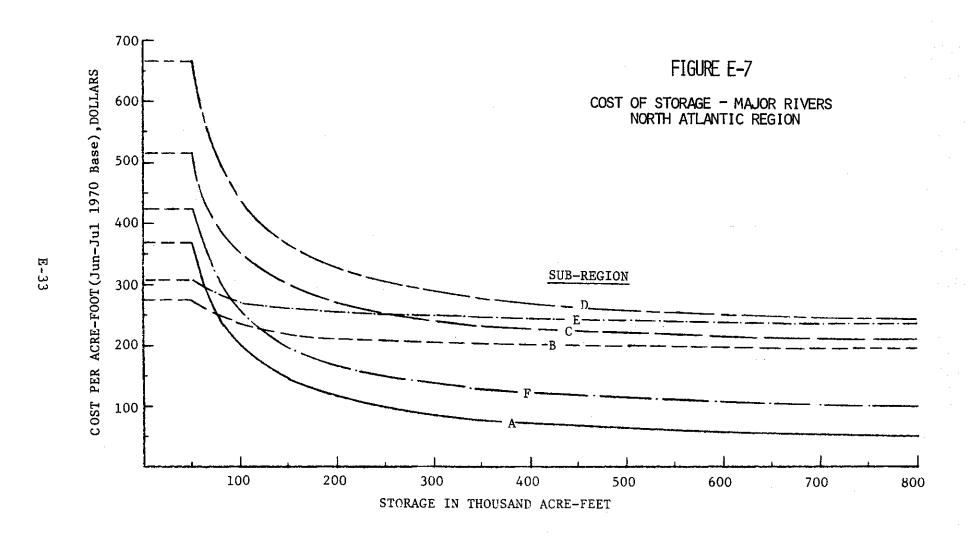
Curves of storage cost per acre-foot based on the above equations adjusted to 1970 price levels are shown in Figure E-7. Because of the linear equations, costs would be unrealistically high for storage less than about 50,000 acre-feet. Accordingly, the cost per acrefoot was assumed to be constant below this point as indicated in the Figure. These capital costs were subsequently converted to annual costs using the capital recovery factor for 5-1/8% interest and assuming 100-year project life. An average value of 12% of capital cost was added for annual operation and maintenance.
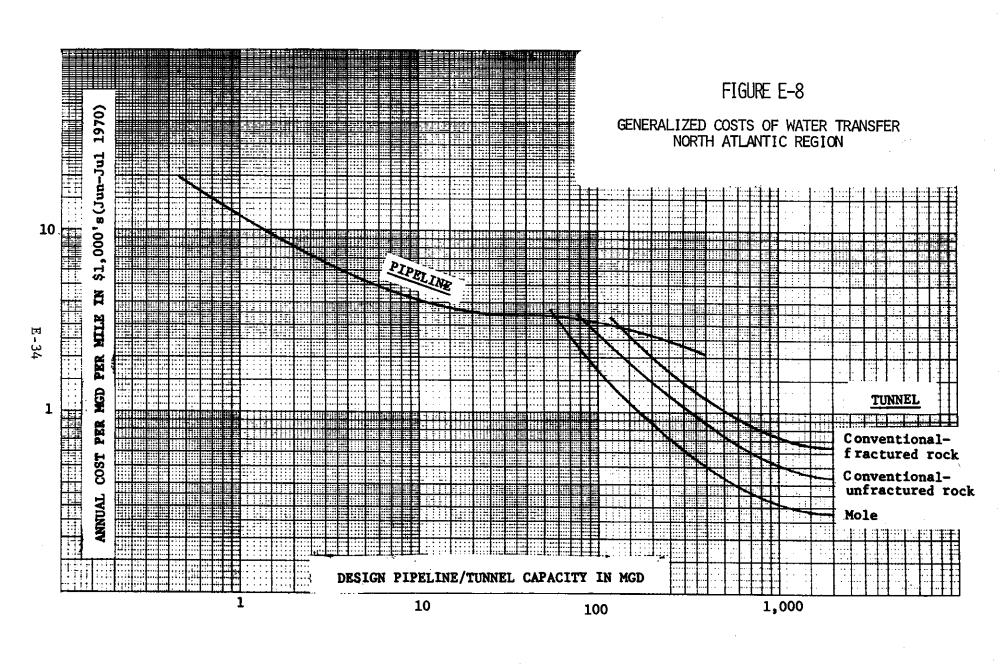
Water Transfer Costs

Estimates of costs of potential inter-basin transfers by pipeline or tunnel are vital in analyses for optimum allocation of resource development. To develop generalized cost criteria, a representative sample of data on pipeline and tunnel capital cost, capacity, operation and maintenance cost, design limitation and geologic information was collected from a variety of engineering feasibility studies to construct a finite set of curves relating pipeline-tunnel design capacity to costs per m.g.d. per mile.

Adopted relationships are shown on Figure E-8. A single generalized pipeline curve could be used since the costs of laying a pipeline a few feet into the ground varied little. Tunnel cost data varied by an order of magnitude depending on the geomorphologic characteristics of a particular area, reflecting differences in the costs between simple machine moling and blasting, and the necessary support structures in fractured bedrock. The smallest economically-feasible internal tunnel diameter is 60 inches, so that the tunnel curves intersect the generalized pipeline curve at some point near a capacity of 70-100 m.g.d. on the graph.

Complete costs of pipelines and tunnels included such items

FIGURE E-7

COST OF STORAGE - MAJOR RIVERS
NORTH ATLANTIC REGION

SUB-REGION

D

E

C

B

F

A

COST PER ACRE-FOOT(Jun-Jul 1970 Base),DOLLARS

STORAGE IN THOUSAND ACRE-FEET

FIGURE E-8

GENERALIZED COSTS OF WATER TRANSFER
NORTH ATLANTIC REGION

ANNUAL COST PER MGD PER MILE IN $1,000's (Jun-Jul 1970)

PIPELINE

TUNNEL

Conventional-
fractured rock

Conventional-
unfractured rock

Mole

DESIGN PIPELINE/TUNNEL CAPACITY IN MGD

10

1

1

10

100

1,000

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as the costs of transportation of materials, excavation, laying of pipeline, testing, miscellaneous fittings, vertical tunnel shafts, profit, engineering costs, and booster pumping, and were derived from the studies previously mentioned for water resource development projects in the Northeastern United States. The costs were converted to an annual basis using a 50-year life. The capital recovery factor using 5 1/8 percent interest rate and taking into account all the associated incidental costs, was 0.07. All costs in addition, were projected to a common ENR index of 1400, representing conditions at approximately the middle of 1970.
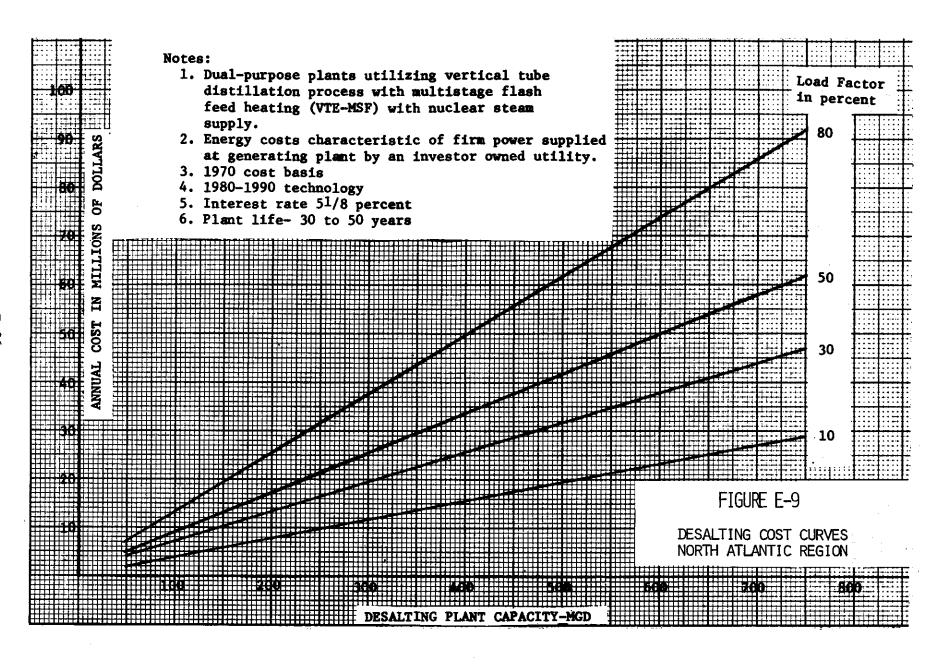
Desalting Costs

A detailed discussion of desalting as a source of water supply, prepared by the Office of Saline Water, is contained in Appendix R, Water Supply. This material and additional back-up information furnished by the Office of Saline Water with available cost data were used in studies to develop relationships of potential desalting plant capacity versus estimated cost for the Region's coastal Sub-areas. This material was designed for use as input to the NAR Supply Model and plan formulation studies in Appendix T.

The primary assumption in the development of desalting cost data for use in NAR analyses is that desalting plants would be operated in conjunction with existing water supply systems. Thus the plants would be used chiefly as a supplemental source of water during shortage periods. As a result, costs are presented in terms of several plant load factors, representing a percentage of the total time that the plant would be in use as a supplemental source. Plant load factors were assumed to be lowest in Areas containing large rivers and streams that are not expected to be extensively regulated. The critical periods of need for additional water should be shortest in these areas. Load factors were considered to be high in areas likely to have highly regulated or very limited conventional sources of supply, and accordingly extended periods of need for supplemental water. Conjunctive operation of desalting plants with multi-unit nuclear power stations for a constant, required energy source was assumed. Curves adopted for use in estimating costs of desalting plants are shown on Figure E-9. This cost includes the costs of the desalting plant only and payment for the energy delivered by the nuclear power station. It should be noted that the costs are projections based on assumed technological improvements in the near future.

Plant life varies inversely with the load factors, so that a plant operating at 10% has an expected life of 50 years, whereas one operating at 80% has a life of 30 years. Capital recovery factors reflect interest rate (5 1/8%), replacement costs and insurance as well as the plant life. The costs of land and water transfers to points of need are not included in Figure E-9.

A general rule of thumb suggested by the Office of Saline Water and the Federal Power Commission is that desalting plant capacity

ANNUAL COST IN MILLIONS OF DOLLARS

Notes:
1. Dual-purpose plants utilizing vertical tube
   distillation process with multistage flash
   feed heating (VTE-MSF) with nuclear steam
   supply.
2. Energy costs characteristic of firm power supplied
   at generating plant by an investor owned utility.
3. 1970 cost basis
4. 1980-1990 technology
5. Interest rate $5^{1}/8$ percent
6. Plant life- 30 to 50 years

Load Factor
in percent

80

50

30

10

FIGURE E-9

DESALTING COST CURVES
NORTH ATLANTIC REGION

DESALTING PLANT CAPACITY-MGD

in m.g.d. should be about one-fifth of the power generation capacity in megawatts. Accordingly, a nuclear power plant of 1,000 megawatts capacity would sustain a desalting plant with a capacity of about 200 m.g.d.

CHAPTER 3. REGIONAL SUMMARY

FLOOD DAMAGE REDUCTION

PRESENT STATUS

Flood damages in the North Atlantic Region, that under natural conditions in January 1966 would have been about $240 million, have been modified by existing and nearly completed projects to about $150 million. (See Table E-5). Residual or existing damages include the effects of Federal and non-Federal flood damage reduction projects, as well as an allowance for any flood reduction effects attributed to projects designed principally for other purposes. Because of difficulties in adjusting observed hydrologic records for the flood reduction effects of some of the older non-Federal reservoirs built for various storage purposes, natural conditions as used in this Appendix also include the effects of these projects in some instances.

If no further action is taken to reduce flood damages, they can be expected to grow from the 1966 annual average of $150 million to an average annual of $900 million by 2020, an approximate six-fold increase. (See Table E-6).

Up to the present, structural means of flood damage reduction have been most heavily relied on in high damage areas. The extent of flood damage reduction is indicated in Table E-5 and on Figures E-10 through E-17 (these figures are at the end of this chapter on page E-53 through E-60).

Passive or non-structural means of flood damage reduction are just beginning to be used with great success in the Region. The growing awareness by both Federal agencies and local governments of the value of flood plain management techniques is illustrated by the growth of the Corps of Engineers' Flood Plain Management Services Program. The backbone of this program is the Flood Plain Information Report, which is prepared only upon the request of State and local governmental agencies. Its purpose is to delineate flood problems, and it provides information on the extent, depth, probability and duration of past floods and those anticipated in the future. In addition to a narrative, the report, includes maps or mosaics, profiles, charts and tables. Each report also describes the possible uses of the information as a basis for developing flood plain regulations or for other means of alleviating flood problems, as well as planning assistance available to local governments.

From the inception of the Flood Plain Management Services Program in 1960 (authorized under Section 206 of the 1960 Flood Control Act, PL 86-645), until 1967, the Army Engineers completed approximately 20 studies in the North Atlantic Region. As of June 1971, 93 reports had been issued, more than 55 were in progress, and some 95 were awaiting

TABLE E-5
AVERAGE ANNUAL FLOOD DAMAGES
(January 1966 Flood Plain Conditions – Values in June 1970 $Millions)

	TOTAL NATURAL CONDITION FLOOD DAMAGES	BENEFITS FROM EXISTING OR NEARLY COMPLETED PROJECTS	BASE 1966 FLOOD DAMAGES[1]
Area 1	0.17	0.0	0.17
Area 2	0.21	0.0	0.21
Area 3	0.48	0.0	0.48
Area 4	1.08	0.0	1.08
Area 5	0.07	0.02	0.05
SUB-REGION A	2.01	0.02	1.99
Area 6	0.49	0.01	0.48
Area 7	9.00	4.97	4.03
Area 8	25.03	18.64	6.39
Area 9	16.44	6.59	9.85
Area 10	25.35	14.49	10.86
SUB-REGION B	76.31	44.70	31.61
Area 11	6.31	0.53	5.78
Area 12	10.64	2.81	7.83
Area 13	32.99	0.0	32.99
SUB-REGION C	49.94	3.34	46.60
Area 14	19.31	0.0	19.31
Area 15	16.16	3.88	12.28
Area 16	4.73	0.0	4.73
SUB-REGION D	40.20	3.88	36.32
Area 17	52.65	41.84	10.81
Area 18	6.35	0.11	6.24
SUB-REGION E	59.00	41.95	17.05
Area 19	7.91	1.42	6.49
Area 20	0.87	0.12	0.75
Area 21	5.40	0.47	4.93
SUB-REGION F	14.18	2.01	12.17
TOTAL NAR	241.64	95.90	145.74

[1] Amount considered existing in 1966, the point from which damages were projected.

TABLE E-6
PROJECTED AVERAGE ANNUAL FLOOD DAMAGES
(Values in 1970 million dollars)

	JANUARY 1966	1980	2000	2020
Area 1	0.17	0.26	0.48	0.98
Area 2	0.21	0.30	0.58	1.15
Area 3	0.48	0.73	1.35	2.76
Area 4	1.09	1.64	3.02	6.29
Area 5	0.05	0.06	0.13	0.25
SUB-REGION A	1.99	2.99	5.54	11.44
Area 6	0.48	0.77	1.48	3.15
Area 7	4.03	6.29	12.17	24.87
Area 8	6.39	9.97	19.50	40.27
Area 9	9.85	15.37	29.36	59.12
Area 10	10.86	17.17	33.25	69.00
SUB-REGION B	31.61	49.57	95.76	196.40
Area 11	5.78	8.90	16.53	33.52
Area 12	7.83	11.75	22.48	44.11
Area 13	32.99	50.14	93.36	179.46
SUB-REGION C	46.60	70.79	132.37	257.08
Area 14	19.31	29.35	54.83	105.22
Area 15	12.28	19.03	36.83	75.87
Area 16	4.73	7.24	13.91	27.82
SUB-REGION D	36.32	55.62	105.57	208.91
Area 17	10.81	16.97	34.15	72.74
Area 18	6.24	10.48	20.08	39.91
SUB-REGION E	17.05	27.45	54.23	112.65
Area 19	6.49	12.52	27.12	60.33
Area 20	0.75	1.32	2.72	5.78
Area 21	4.93	8.48	17.11	36.00
SUB-REGION F	12.17	22.32	46.95	102.11
TOTAL NAR	145.74	228.74	440.42	888.59

funding. Of the 93 completed reports, more than 90% have been used by local governments for regulatory or other purposes (See Table E-7, p.E-43). As the program passed from the planning state into implementation, operation and maintenance, the number of involved agencies increased. Federal agencies involved in the program include the Departments of Agriculture, Commerce, Housing and Urban Development, the Interior, the Office of Emergency Preparedness and the partially-Federal river basin commissions.

PROJECT ACCOMPLISHMENTS

Existing projects for flood damage reduction have reduced damages in a number of Areas. Greatest reductions have occurred in Areas 8, 9, 10, and 17, with Area 17 having by far, the most notable reduction. (See Table E-5). Details on projects are shown on the individual Area summaries and locations are shown on Figure E-67 (p.E-176) and Figure E-68 (p. E-177).

High flood damages tend to occur in those stream reaches with the highest pressures for development in the flood plain. Such pressures can be generated by either a large population creating a shortage of land, or by a small population and little attractive land, other than in the valleys in extremely mountainous regions. Both types of areas are represented in the Region. Extremes of these cases are presented between Areas such as Area 14 and Area 17. Fortunately, structural measures have proven to be suitable in Area 17 because of little competition for other land use and have greatly reduced damages there.

The accomplishments of non-structural measures, as indicated by the Flood Plain Management Services Program, are modest to date but accelerating in growth. Emphasis has been placed upon the adoption of flood plain regulations and comprehensive land-use planning, with interim control of flood plain use. The uses made of Flood Plain Information Reports are shown in Table E-7.

Tidal and hurricane flooding tends to be a large portion of the damage in coastal areas. It is a serious problem, particularly in those Areas where high population and recreation pressures are stimulating development in the coastal flood plains. Areas 9, 10, 13, 16 and 18 have the most severe need for reduction of tidal flood damages with the need being by far the largest in Area 13.

More detailed information on damages on flooding characteristics is presented in Chapter 4, Area Summaries.

FUTURE CONDITIONS

The magnitude of the flood problem in the future will be largely a function of the effectiveness of land-use controls adopted

USES OF FLOOD PLAIN INFORMATION REPORTS

Completed	FPI REPORTS	Used
93	Number of Reports	84

Covered	COMMUNITIES	Used Reports
99	Number of Counties	83
151	Number of Urban Places	122
170	Number of Non-urban Places	149
420	TOTAL COMMUNITIES	354

USES MADE OF FPI REPORTS

Flood Plain Regulations:

Flood plain regulations adopted	40
Flood plain regulations revised for more effective management	5
Existing flood plain regulations effectuated	39
Flood plain regulations in process of being adopted	25
Flood plain regulations under Study	91
TOTAL FLOOD PLAIN REGULATIONS	200

Other:

Interim control of flood plain use	123
Flood control works by non-Federal interests	0
Flood control studies by non-Federal interests underway	28
Guide for acquisition of flood plain lands	18
Comprehensive land-use planning	153

and enforced by local and State governments with the aid of Federal agencies. The era of solely controlling flood waters is passing and unrestrained damages will be reduced largely by effective control of the extent and type of future development in the flood plain. The 2020 potential annual damage reduction tabulation which follows, indicates that more than 45% of 2020 unrestrained annual damages can reasonably be expected to be avoided by management measures, whereas only about a 33% reduction is forecast for existing and potential projects.

In the North Atlantic Region, any desirable single-purpose flood control sites have been preempted for other uses, construction costs are high, and the locational advantages of the flood plain are diminishing due, in part, to improved transportation and communication to alternative areas. In addition, public and governmental opposition is strong and growing stronger because of costs, other than construction costs, which are passed on to the public. Included are social, environmental and economic costs.

During the third round of plan formulation, it became evident that storage structures designed principally for flood control protection are not a feasible alternative to management. Therefore, the Area Summaries do not show damage reduction from new storage structures, although data are presented elsewhere in this Appendix as a means of rapidly evaluating future damage reduction through the inclusion of flood control in multiple-purpose storage projects and the changing needs of future re-studies.

Future conditions described in each Area Summary consider damage reduction by an appropriate amount and combination of structural and non-structural measures. The mix is shown to vary somewhat with objective. Regional, Sub-regional and Sub-area summaries of projected average annual damages are shown in Figures E-10 through E-17 (pages E-53 through E-60).

The nature of potential reduction of annual damage in 2020 is indicated by the following summary for the NI Objective:

SUB-REGION	Annual Damage	Reduction from Structures	Reduction from Management	Residual Damage
A	11.4	0.8	8.7	1.9
B	196.4	62.8	110.4	23.2
C	257.1	50.1	119.2	87.8
D	208.9	134.8	48.3	25.8
E	112.7	25.0	65.9	21.8
F	102.1	22.0	61.4	18.7
TOTAL NAR	888.6	295.5	413.9	179.2

(all values in millions of dollars, June 1970)

There are several means of effecting flood damage reduction under flood plain management, including the following.

- Designation of floodways and encroachment lines where no construction or landfill should be permitted.
- Zoning for optimal land-use, both inside and outside the flood plain.
- Sub-division regulations for controlling construction in presently undeveloped areas.
- Building codes to reduce flood damages to buildings in the flood plain.
- Development policies.
- Floodproofing for reduction and elimination of flood damages by structural changes and adjustments. Applicable to both new and existing buildings.
- Flood forecasting and temporary evacuation.
- Permanent evacuation and relocation.
- Open space for recreational use in the flood plain.
- Urban redevelopment (renewal).
- Warning signs to inform prospective buyers that a flood hazard exists.
- Tax adjustments to encourage wise land use.
- Construction financing by private and Federal institutions to control flood plain development.
- Flood insurance.

SUMMARY

The need exists for continued effort to reduce flood damages in the Region. Flooding has been and will continue to be a serious problem.

Structural measures where required should be mutiple-purpose in nature if possible. In addition, storage structures built for flow management or other purposes should be investigated for flood damage reduction wherever possible.

Flood plain management measures should be encouraged in all Areas to the maximum extent consistent with Area objectives and development needs. Flood plain management is concluded to be not only aesthetically appealing but the most efficient in terms of benefits and costs.

In addition to on-going studies and programs, new comprehensive studies which would include flood control appear needed in Areas 7 and 12. Continued studies will be required in the highly urban areas, particularly Areas 13 and 14, where major structural measures have the least likelihood of success. Particular emphasis should be given to studies of new or more effective means of land use and flood plain management. Success in management efforts will pay high dividends in terms of reducing the total North Atlantic Region's flood damages.

In addition to the high need for tidal and hurricane protection in Area 13, hurricane protection studies in Areas 9, 10, 16 and 18 are needed. Future updating is a recognized need for completed or on-going comprehensive studies in Areas 8, 15, 17, 19 and 21.

WATER MANAGEMENT

The methodology discussed in the preceding chapter was used to derive a practical limit of development for each Area and the Region. The potential upstream and major river surface development as shown in Tables E-8, E-9, and E-10 was combined with potential additional ground water and the presently available firm resource, resulting in the practical development limits shown in Table E-11. Additional information is contained in Chapter 4, Area Summaries.

PRESENT STATUS

The resource assumed to be available on a sustained basis for withdrawal and instream needs is indicated by the values shown in Column 3 of Table E-11. These quantities are based on the minimum flow data developed in Appendix C, where minimum streamflow or outflow is approximately equivalent to seven-day, 50-year occurrences, while the yield from any major storage not reflected in the existing outflow is based on the previously described yield-storage relationships and a shortage index of 0.01 (As a result of adopting this yield criteria, the information presented may vary somewhat from data in other sources.) In order to set forth the resource available before use, allowances are included for existing consumption, the yield of reservoirs used for inter-Area diversion and, in the case of Area 13, ground water not reflected in surface outflow. Consumption was taken from the Appendix T demand model analysis of 1965 conditions.

An indication of existing reservoir development for all purposes is given in the following tabulation derived principally from Geological Survey Water-Supply Paper 1838, "Reservoirs in the United States," by R.O.R. Martin and Ronald L. Hanson. Projects of 5,000 acre-feet or more of usable storage completed or under construction as of January 1, 1963 were considered in this paper. For the purposes of the NAR Study, projects completed since this date or under construction were added to the data in the referenced publication. These included Round Valley and Spruce Run Reservoirs in Area 14, Cannonsville in Area 15, Raystown in Area 17, and Gathright in Area 21.

SUB-REGION	USABLE STORAGE (1,000 Acre-feet)
A	4,855
B	4,503
C	2,583
D	1,815
E	1,759
F	277
TOTAL NAR	15,792

TABLE E-8
PRACTICAL DEVELOPMENT STORAGE POTENTIAL – MAJOR RIVERS [1]
(Number of sites/Total storage in 1,000 acre-feet)

	MORE THAN 600,000 AF	301,000 – 600,000 AF	101,000 – 300,000 AF	51,000 – 100,000 AF	20,000 – 50,000 AF	LESS THAN 20,000 AF	TOTALS
Area 1	1/2,900	1/535	–	–	–	–	2/3,435
Area 2	–	2/930	1/180	2/150	1/40	–	6/1,300
Area 3	–	–	4/630	–	–	–	4/630
Area 4	–	1/330	2/330	–	3/60	–	6/720
Area 5	–	–	–	1/100	4/110	–	5/210
SUB-REGION A	1/2,900	4/1,795	7/1,140	3/250	8/210	–	23/6,295
Area 6	–	–	1/200	–	2/67	–	3/267
Area 7	–	–	2/287	3/218	2/95	–	7/600
Area 8	–	–	1/126	9/572	16/532	11/148	37/1,378
Area 9	–	–	–	1/82	–	3/31	4/113
Area 10	–	–	1/169	3/174	4/96	–	8/439
SUB-REGION B	–	–	5/782	16/1,046	24/790	14/179	59/2,797
Area 11	–	–	3/361	3/212	2/49	1/13	9/635
Area 12	–	2/914	3/601	5/380	2/61	1/16	13/1,972
Area 13	–	–	–	–	–	–	–
SUB-REGION C	–	2/914	6/962	8/592	4/110	2/29	22/2,607
Area 14	–	–	–	3/159	1/21	3/39	7/219
Area 15	–	–	1/200	4/258	15/478	1/15	21/951
Area 16	–	–	–	–	1/25	1/15	2/40
SUB-REGION D	–	–	1/200	7/417	17/524	5/69	30/1,210
Area 17	–	1/330	5/795	15/1,030	14/538	2/30	37/2,723
Area 18	–	–	–	–	–	–	–
SUB-REGION E	–	1/330	5/795	15/1,030	14/538	2/30	37/2,723
Area 19	–	–	3/453	8/566	–	–	11/1,019
Area 20	–	1/461	1/151	1/74	–	–	3/686
Area 21	–	1/407	2/497	1/88	–	–	4/992
SUB-REGION F	–	2/868	6/1,101	10/728	–	–	18/2,697
TOTAL NAR	1/2,900	9/3,907	30/4,980	59/4,063	67/2,172	23/307	189/18,329

[1] The following existing projects are noy included: Beltzville and Tocks Island in Area 15, Raystown in Area 17 and Gathright in Area 21.

TABLE E-9

PRACTICAL DEVELOPMENT STORAGE POTENTIAL - UPSTREAM AREAS

	NUMBER OF SITES	STORAGE (1,000 Acre-feet)	GROSS YIELD (m.g.d.)
Area 1	33	301.3	287
Area 2	51	630.9	601
Area 3	62	605.9	577
Area 4	63	621.9	593
Area 5	81	880.3	1,144
SUB-REGION A	290	3,040.3	3,202
Area 6	121	701.8	911
Area 7	227	768.1	997
Area 8	349	1,219.0	1,582
Area 9	87	219.7	285
Area 10	96	211.9	276
SUB-REGION B	880	3,120.5	4,051
Area 11	255	497.7	623
Area 12	267	1,603.6	2,083
Area 13	–	–	–
SUB-REGION C	522	2,083.3	2,706
Area 14	63	276.3	329
Area 15	348	999.6	1,190
Area 16	20	87.4	156
SUB-REGION D	431	1,363.3	1,675
Area 17	541	1,723.1	2,237
Area 18	76	267.1	294
SUB-REGION E	617	1,990.2	2,531
Area 19	407	776.2	616
Area 20	225	733.8	583
Area 21	265	1,445.4	1,147
SUB-REGION F	897	2,955.4	2,346
TOTAL NAR	3,637	14,553.0	16,511

NET YIELD FROM PRACTICAL DEVELOPMENT STORAGE
(All figures in m.g.d.)

	MAJOR RESERVOIRS	UPSTREAM RESERVOIRS	ADJUSTED TOTAL
Area 1	2,530	252	2,757
Area 2	2,440	531	2,823
Area 3	400	495	859
Area 4	877[1]/	465	1,139
Area 5	385	946	1,282
SUB-REGION A	6,632	2,689	8,860
Area 6	452	712	1,095
Area 7	1,440[1]/	820	1,984
Area 8	1,875	1,217	2,922
Area 9	79	213	290
Area 10	562	222	755
SUB-REGION B	4,408	3,184	7,046
Area 11	922	348	1,250
Area 12	3,883[1]/	1,830	4,974
Area 13	–	–	–
SUB-REGION C	4,805	2,178	6,224
Area 14	325	280	550
Area 15	1,295[1]/	948	2,094
Area 16	85	117	199
SUB-REGION D	1,705	1,345	2,843
Area 17	3,879[1]/	2,045	5,537
Area 18	–	222	222
SUB-REGION E	3,879	2,267	5,759
Area 19	1,441[1]/	508	1,864
Area 20	913	568	1,359
Area 21	831	1,001	1,702
SUB-REGION F	3,185	2,077	4,925
TOTAL NAR	24,614	13,740	35,657

[1]/ Yield for Sub-areas 4a, 7a, 12b, 15b, 17e and 19c based on yield-storage relationships at respective Sub-area outlets.

TABLE E-11
TOTAL PRACTICAL DEVELOPMENT RESOURCE
(All figures in m.g.d.)

	DRAINAGE AREA (Sq. miles)[1] (1)	AVERAGE ANNUAL RUNOFF (2)	EXISTING RESOURCE[2] (3)	ADD'L YIELD FROM STORAGE (4)	ADD'L YIELD FROM GROUND WATER			TOTAL PRACTICAL (3)+(4)+(7)
					RURAL (5)	M & I (6)	TOTAL[3] (7)	
Area 1	11,455	12,115	828	2,757	322	848	395	3,980
Area 2	8,525	9,650	2,568	2,823	391	635	423	5,814
Area 3	5,870	6,500	1,657	859	274	515	300	2,816
Area 4	3,450	3,985	1,124	1,139	158	402	179	2,442
Area 5	6,856	7,510	1,029	1,282	268	54	271	2,582
SUB-REGION A	36,156	39,770	7,206	8,860	1,413	2,454	1,568	17,634
Area 6	4,208	4,615	596	1,095	175	469	198	1,889
Area 7	5,050	5,380	670	1,984	225	295	240	2,894
Area 8	11,250	12,230	1,697	2,922	438	1,210	540	5,159
Area 9	4,576	5,280	800	290	733	176	742	1,832
Area 10	4,555	4,870	394	755	191	361	224	1,373
SUB-REGION B	29,639	32,375	4,157	7,046	1,762	2,511	1,944	13,147
Area 11	11,900	12,145	1,640	1,250	475	689	583	3,473
Area 12	13,366	13,190	2,261	4,974	509	1,066	603	7,838
Area 13	1,901	1,900[4]	623	--	--	654[5]	589	1,212
SUB-REGION C	27,167	27,235	4,524	6,224	984	2,409	1,775	12,523
Area 14	2,376	2,580	852	550	23	443	94	1,496
Area 15	12,765	13,200	4,840	2,094	320	1,475	628	7,562
Area 16	2,393	2,450	845	199	--	188	21	1,065
SUB-REGION D	17,534	18,230	6,537	2,843	343	2,106	743	10,123
Area 17	27,510	24,890	1,741	5,537	923	4,230	1,478	8,756
Area 18	8,145	5,500	1,085	222	61	730	161	1,468
SUB-REGION E	35,655	30,390	2,826	5,759	984	4,960	1,639	10,224
Area 19	14,670	8,970	776	1,864	482	1,696	912	3,552
Area 20	6,000	3,680	78	1,359	189	173	265	1,702
Area 21	10,600	7,450	674	1,702	379	783	562	2,938
SUB-REGION F	31,270	20,100	1,528	4,925	1,050	2,652	1,739	8,192
TOTAL	177,421	168,100	26,778	35,657	6,536	17,092	9,408	71,843
TOTAL NAR	172,586	162,930	26,286	35,657	6,536	17,092	9,408	71,351

[1] Includes contributing drainage area in Canada (4,096 square miles in Area 1, 625 square miles in Area 5, and 114 square miles in Area 8) except for last line, TOTAL NAR, which is U.S. only.

[2] Available before use; includes allowance for consumption, yield of existing storage, and yield of the following authorized projects: Beltzville and Tocks Island in Area 15, Raystown in Area 17, and Gathright in Area 21. Flow developed for export is included in resource of the originating Area. See Chapter 4, Area Summaries, for additional information.

[3] Effective total; i.e., the portion of practical development assumed additive to existing resource after allowance for existing ground water use and subtractive effects.

[4] Includes estimate of sub-surface outflow of ground water.

[5] Includes 300 m.g.d. anticipated artificial recharge.

Additional storage is available in numerous smaller upstream reservoirs.

Although complete records are not generally available on ground water use by NAR Areas or Sub-regions, the following tabulation has been synthesized from the partial information available in several sources, including Appendix R and the demand model analyses, in order to provide the approximate extent of existing (1965) average ground water use:

SUB-REGION	GROUND WATER USE (m.g.d.)
A	40
B	500
C	590
D	810
E	390
F	170
TOTAL NAR	2,500

DEVELOPMENT POTENTIAL

Resource management measures for increasing the supplies of water can involve a variety of approaches. The more conventional means such as providing additional surface storage and ground water are discussed in some detail in this Appendix and in Appendix C, Appendix D and Appendix F. These techniques, and artificial recharge and desalting to a lesser extent, have been used as feasible solutions. Investigation and research of other measures such as weather modification for management of precipitation, land management for control of evapotranspiration and runoff, suppression of evaporation from lakes and reservoirs, and use of underground storage, should be continued so that they can be more fully considered in subsequent studies. While these measures all have the potential for increasing available water supplies under certain circumstances, the costs, yields and side effects cannot be assessed to the degree necessary for application to these analyses. Emphasis is also needed on the management of demand. This includes practices such as reduction of waste, reclamation of water, repeated re-use, recycling, and adjustment of prices.

The potential for existing storage and ground water development for water management other than flood control is summarized in Table E-11. In accordance with methodology previously discussed, net yields from potential reservoir and ground water development have been added to the existing available resource to determine an upper limit of practical development in each Area. The practical development limits vary from about 27% to 64% of average annual runoff and the Regional value, including Canadian drainage, is about 43%.

The information in Table E-11 sets theoretical upper limits

or bounds of development which, under current conditions, would appear attainable. However, these limits are only approximations. It is recognized the under conditions approaching full development, hydrologic systems would be substantially changed in some cases. For example, some reduction in yield would be likely since lake and reservoir evaporation is generally somewhat greater than normal evapotranspiration in the areas replaced by reservoirs. On the other hand, increased ground water use would tend to reduce losses due to evapotranspiration as well as induce higher recharge of aquifers during non-low flow seasons.

Using the methodology described on desalting in conjunction with multi-unit nuclear power stations and Federal Power Commission projections of Regional power plant construction and sites, estimates were made of the approximate practical limit for desalting in NAR coastal Sub-areas. The following tabulation indicates the results by Sub-region:

SUB-REGION	DESALTING POTENTIAL (m.g.d.)
A	100
B	1,400
C	950
D	1,550
E	550
F	900
TOTAL NAR	5,450

SUMMARY

It is technically practical to achieve an increase in available resource or firm yield of almost 200%. In comparison with the existing firm resource of about 26 b.g.d., additional development of surface and ground water could account for approximately 45 b.g.d., and desalting, over 5 b.g.d. The portion of the practical developable resource that will be needed during the planning period depends largely on the projected demands resulting from the NAR Demand Model analyses.

The data in this Appendix on available resource and the potential for surface storage, ground water, and desalting, together with appropriate cost functions for each source and for potential water transfers, define the resource imput to the supply model studies of Appendix T. In these studies, analysis of the development necessary to satisfy future withdrawal and instream needs is made on the basis of least cost. For the model analyses, certain relatively small modifications are made in the process of developing the cost functions for each of the 50 Sub-areas, and in accounting for specified controlling contraints and bounds. This will be further discussed in the Supply Model Annex to Appendix T.

NOTE:
AVERAGE ANNUAL
DAMAGE VALUES ARE IN
MILLIONS OF DOLLARS
(JUNE 1970 PRICES)

NORTH ATLANTIC REGIONAL
WATER RESOURCES STUDY
**FLOOD DAMAGES
PRESENT and PROJECTED**

LEGEND:
$
TOTAL DAMAGE
(NATURAL CONDITIONS)

$
REDUCTION BY
NEARLY COMPLETED
OR EXISTING
PROJECTS

$
RESIDUAL DAMAGE
(1966 CONDITIONS)

$
REDUCTION OF
2020 DAMAGES BY
POTENTIAL PROJECTS
(NE OBJECTIVE)

1966 1980 2000 2020

AVERAGE ANNUAL DAMAGE DISTRIBUTION AND PROJECTION

FIGURE E-10

FIGURE E-11

AVERAGE ANNUAL DAMAGE DISTRIBUTION AND PROJECTION

$0.17

100%

$0.17

$0.21

100%

$0.21

$0.48

100%

$0.48

$1.08

$100%

$1.08

$0.07

0.02 29%
71%

$0.05

$0.18

18%

1

$0.00
0%

2

$0.00
0%

3

$0.66

11%

4

$0.00
0%

5

NOTE:
AVERAGE ANNUAL
DAMAGE VALUES ARE IN
MILLIONS OF DOLLARS
(JUNE 1970 PRICES)

CANADA

ST. JOHN RIVER

①

②

⑤

④ ③ A

MAINE N.H. ANDROSCOGGON

PENOBSCOT RIVER

KENNEBEC RIVER

AUGUSTA

SUB-REGION A
AREAS ①-⑤
FLOOD DAMAGES
PRESENT and PROJECTED

SCALE

LEGEND:

$
TOTAL DAMAGE
(NATURAL CONDITIONS)

$
REDUCTION BY
NEARLY COMPLETED
OR EXISTING
PROJECTS

$
RESIDUAL DAMAGE
(1966 CONDITIONS)

$
REDUCTION OF
2020 DAMAGES BY
POTENTIAL PROJECTS
(NE OBJECTIVE)

1966 1980 2000 2020

AVERAGE ANNUAL DAMAGE DISTRIBUTION AND PROJECTION

1

$0.98
$0.48
$0.17 $0.26
1966 1980 2000 2020

2

$1.15
$0.58
$0.21 $0.30
1966 1980 2000 2020

3

$2.76
$1.35
$0.48 $0.73
1966 1980 2000 2020

4

$6.29
$3.02
$1.09 $1.64
1966 1980 2000 2020

5

$0.25
$0.13
$0.05 $0.06
1966 1980 2000 2020

FIGURE E-12

E-55

SUB-REGION B
AREAS ⑥-⑩
FLOOD DAMAGES
PRESENT and PROJECTED

AVERAGE ANNUAL DAMAGE DISTRIBUTION AND PROJECTION

FIGURE E-13

NOTE:
AVERAGE ANNUAL
DAMAGE VALUES ARE IN
MILLIONS OF DOLLARS
(JUNE 1970 PRICES)

$6.3
$0.5
8%
92%
$5.8

$3.1
9%

11

$10.6
$2.8 — 26%
74%
$7.8

$5.5
13%

12

$33.0

100%

$33.0

$41.5
23%

13

SUB-REGION C
AREAS (11)-(13)
FLOOD DAMAGES
PRESENT and PROJECTED

SCALE

11

$5.8 $8.9 $16.5 $33.5

1966   1980   2000   2020

12

$7.8 $11.8 $22.5 $44.1

1966   1980   2000   2020

13

$33.0 $50.1 $93.4 $179.5

1966   1980   2000   2020

LEGEND:
$
TOTAL DAMAGE
(NATURAL CONDITIONS)

$
REDUCTION BY
NEARLY COMPLETED
OR EXISTING
PROJECTS

$
RESIDUAL DAMAGE
(1966 CONDITIONS)

$
REDUCTION OF
2020 DAMAGES BY
POTENTIAL PROJECTS
(NE OBJECTIVE)

1966 1980 2000 2020

AVERAGE ANNUAL DAMAGE DISTRIBUTION AND PROJECTION

FIGURE E-14

E-57

$19.3

100%

$19.3

$16.2

$3.9

24%

76%

$12.3

$4.7

100%

$4.7

$98.7

94%

14

$25.4

33%

15

$10.7

38%

16

D

14

15

TRENTON

PHILADELPHIA

DELAWARE RIVER

PA.
MD.

DEL.
MD.

DOVER

DELAWARE BAY

16

SUB-REGION D
AREAS 14 - 16

FLOOD DAMAGES
PRESENT and PROJECTED

14

$105.2

$54.8

$29.4

$19.3

1966 1980 2000 2020

15

$75.9

$36.8

$19.0

$12.3

1966 1980 2000 2020

16

$27.8

$13.9

$7.2

$4.7

1966 1980 2000 2020

LEGEND:

$
TOTAL DAMAGE
(NATURAL CONDITIONS)

$

REDUCTION BY
NEARLY COMPLETED
OR EXISTING
PROJECTS

$
RESIDUAL DAMAGE
(1966 CONDITIONS)

$

REDUCTION OF
2020 DAMAGES BY
POTENTIAL PROJECTS
(NE OBJECTIVE)

1966 1980 2000 2020

AVERAGE ANNUAL DAMAGE DISTRIBUTION AND PROJECTION

FIGURE E-15

NOTE:
AVERAGE ANNUAL
DAMAGE VALUES ARE IN
MILLIONS OF DOLLARS
(JUNE 1970 PRICES)

E

17

$72.7

$34.2

$17.1

$10.8

1966 1980 2000 2020

$52.7

$41.8

79%

21%

$10.3

17

$17.5

24%

18

$39.9

$20.1

$10.5

$6.2

1966 1980 2000 2020

$6.3

$0.1
2%

98%

$6.2

18

$7.5

19%

SUB-REGION E
AREAS 17 - 18

FLOOD DAMAGES
PRESENT and PROJECTED

SCALE

LEGEND:

$
TOTAL DAMAGE
(NATURAL CONDITIONS)

$
REDUCTION BY
NEARLY COMPLETED
OR EXISTING
PROJECTS

$
RESIDUAL DAMAGE
(1966 CONDITIONS)

$
REDUCTION OF
2020 DAMAGES BY
POTENTIAL PROJECTS
(NE OBJECTIVE)

1966 1980 2000 2020

AVERAGE ANNUAL DAMAGE DISTRIBUTION AND PROJECTION

FIGURE E-16

E-59

NOTE:
AVERAGE ANNUAL DAMAGE VALUES ARE IN MILLIONS OF DOLLARS (JUNE 1970 PRICES)

SUB-REGION F
AREAS (19)-(21)
FLOOD DAMAGES
PRESENT and PROJECTED

LEGEND:
$ TOTAL DAMAGE (NATURAL CONDITIONS)

$ REDUCTION BY NEARLY COMPLETED OR EXISTING PROJECTS
$ RESIDUAL DAMAGE (1966 CONDITIONS)

$ REDUCTION OF 2020 DAMAGES BY POTENTIAL PROJECTS (NE OBJECTIVE)

AVERAGE ANNUAL DAMAGE DISTRIBUTION AND PROJECTION

FIGURE E-17

CHAPTER 4. AREA SUMMARIES

FIGURE E-18

AREA I   ST. JOHN RIVER BASIN

AREA 1. ST. JOHN RIVER BASIN

The St. John River drains a total of 11,455 square miles, with 7,359 square miles in the State of Maine and 4,096 square miles in Canada. Sub-area 1a includes the main stem St. John River in Maine and contains 4,330 square miles of drainage, while Sub-area 1b includes Aroostook River drainage, and tributaries to the south in Maine, some 3,029 square miles.

The principal existing storage in Area 1 is in the Aroostook Basin, where almost 100,000 acre-feet are used for power purpose. Existing storage in Canada of almost 122,000 acre-feet is also used for power.

FLOOD DAMAGE REDUCTION

Area 1 flood damages are caused by flooding along the main river and major tributaries. Average annual damages, under January 1966 conditions, are distributed as follows: St. John River - 41%, and Aroostook River - 59%.
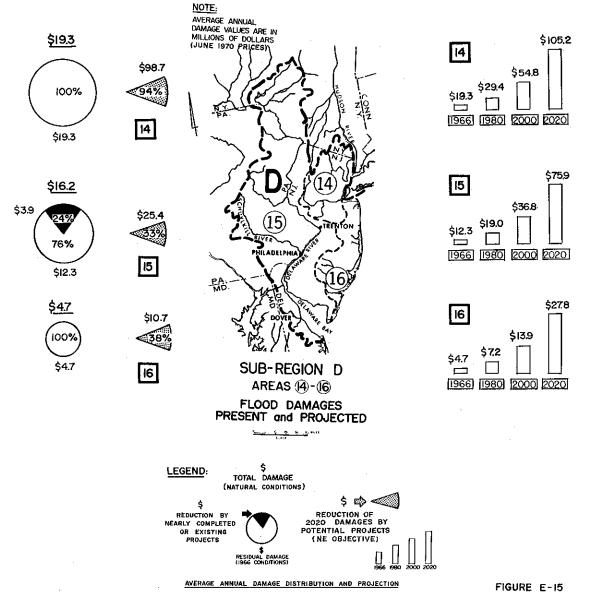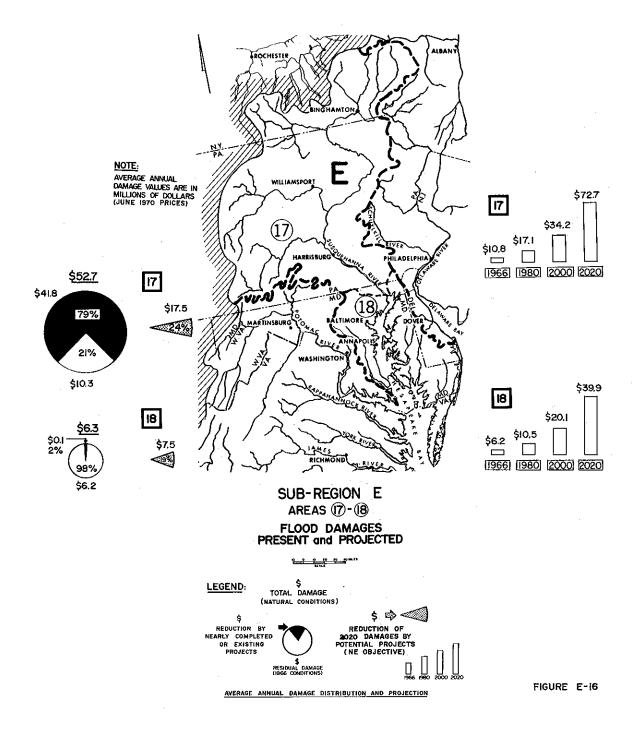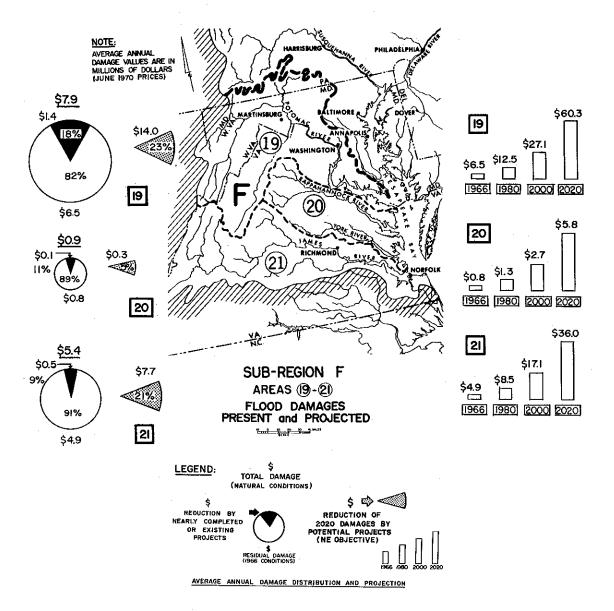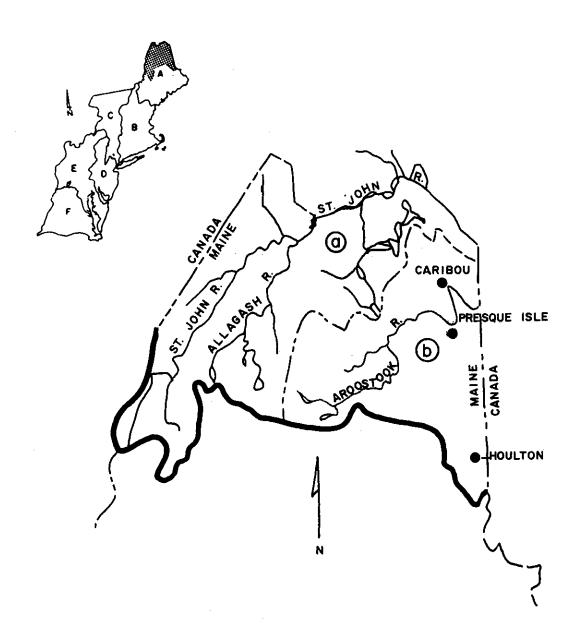
Flood damages are low in the St. John Basin. Natural storage in the headwaters, the heavily forested upper two-thirds of the watershed, and the wide, deep-banked channel of the main stem St. John, have combined to minimize flooding. Heavy spring rains, combined with snowmelt and river ice breakup, are responsible for most of the overbank flow and resultant flood damages.

The most severe floods of record occurred on May 16 and 17, 1961, on the St. John and the Allagash Rivers; and on March 22, 1936, on the Aroostook. Record floods on the main stems of both the St. John and the Aroostook Rivers have generally ranged from 10 to 15 times the average streamflows, with record floods on unregulated tributaries ranging from 20 to 25 times average flows. Those tributaries which are regulated by lakes and ponds generally have record floods on the order of from 10 to 15 times average streamflows.

No differences in flood damage reduction programs for the three planning objectives were apparent in this Area.

The authorized Dickey-Lincoln School Project was considered as constructed and effective in reducing flood damages by 1980. This project will reduce flood flows at Fort Kent below the zero damage stage for all anticipated flows. It was also assumed, because of the relatively undeveloped nature of the Area and an expected slow rate of future flood plain growth, that flood plain management would be less likely than average to succeed here. Therefore, an effectiveness factor of 20% has been used, and is considered attainable if emphasis is placed on non-structural means of reducing damages.

The status of Federal flood damage reduction projects in Area 1 is shown in Table E-11.

TABLE E-12
STATUS OF FLOOD DAMAGE REDUCTION PROJECTS - AREA 1

FLOOD STORAGE PROJECTS
(Map Symbol ▫)

AUTHORIZED (See Figure E-68)

Project	Map Number	Total Storage (Acre-feet)	Flood Control Storage (Acre-feet)	Estimated Total Cost ($1,000)	Year Authorized	River
Dickey-Lincoln School	1	7,661,000	1/	273,000	1965	St. John

1/ No specific storage alloted for flood control

WATER MANAGEMENT

Average annual runoff in Area 1, including drainage from about 4,100 square miles of contributing area in Canada, is approximately 12,115 m.g.d. The existing maximum monthly flow (shortage index 0.01) is 1,220 m.g.d. and the corresponding seven-day minimum is about 68% of this total, or 824 m.g.d. (See Appendix C). The addition of 4 m.g.d. as an allowance for consumptive losses results in an existing firm resource available for use of about 828 m.g.d., or 7% of the average runoff.

The practical limit of development within the Area, based on potential yield of new surface storage and additional ground water, would provide a maximum available resource of 3,980 m.g.d., or 33% of the average runoff. Considering the U.S. portion only, the practical limit would be equivalent to almost 47% of the average runoff. Potential sources which would develop the increase of 3,152 m.g.d., include major storage, accounting for 79% of the increase; upstream storage, 8%, and ground water development, 13%.

PROJECTED FLOOD DAMAGE
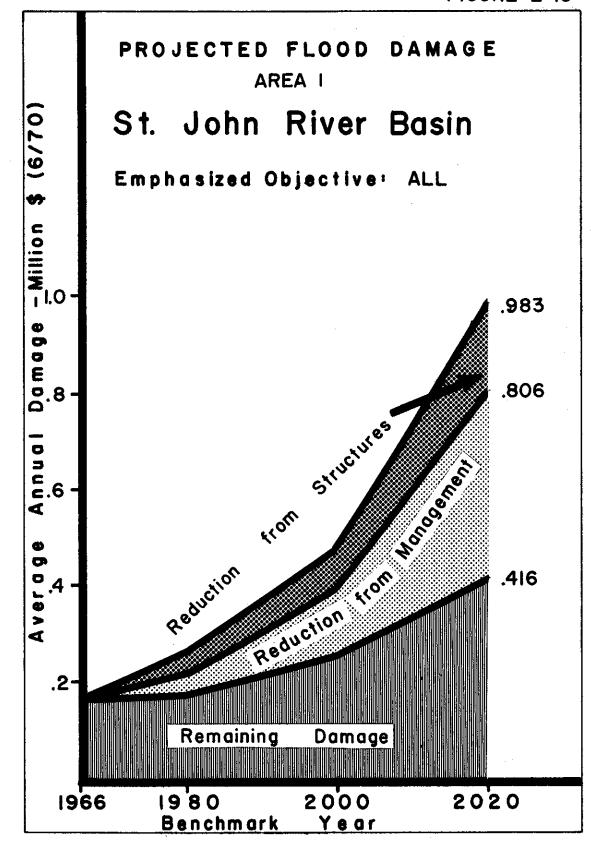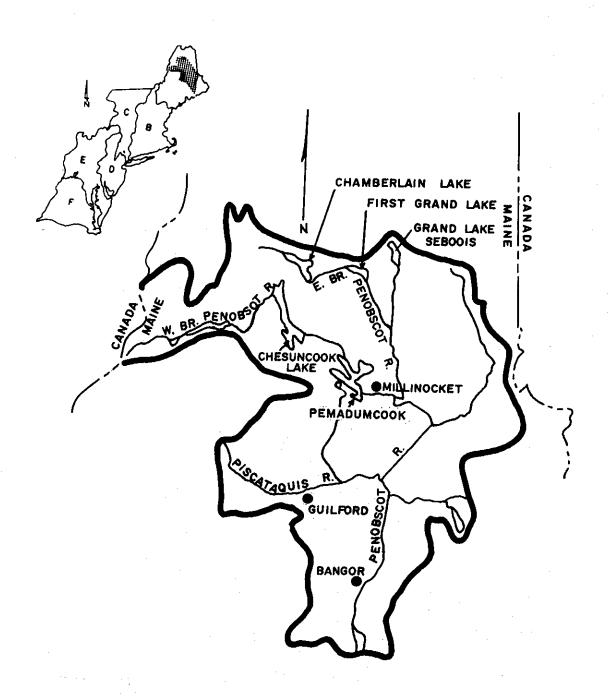AREA I
St. John River Basin
Emphasized Objective: ALL

FIGURE E-20

AREA 2   PENOBSCOT RIVER BASIN

AREA 2. PENOBSCOT RIVER BASIN

The Penobscot River Basin, lying entirely with the State of
Maine, has a drainage area of about 8,525 square miles. Existing us-
able storage capacity amounts to about 1.7 million acre-feet, 80% of
which is located in the West Branch Penobscot River, and was developed
for power and log-driving. All of the storage on the East Branch,
about 157,000 acre-feet, was developed for the same purposes. The
Piscataquis and Mattawamkeag Rivers contain about 200,000 acre-feet
operated for power purposes.

FLOOD DAMAGE REDUCTION

Area 2 flood damages, which are relatively low, include only
those caused by main stem and major tributary flooding. Hurricane,
coastal stream and tidal flood damages are minimal and are not con-
sidered in this summary. While there are no existing flood damage re-
duction structures in the Penobscot Basin, flood flows throughout are
regulated by numerous lakes, ponds and small reservoirs built for
varied purposes. As in Area 1, most flooding is caused by spring rains
coupled with snowmelt and river ice breakup.

The most severe flood of record occurred in 1923 on April 30
and May 1 and 2, causing estimated damages of $1.3 million. Record
flows on the main stem generally range from 10 to 15 times the average
streamflow, with flooding on major tributaries about 15 times average
flows.

No significant differences in flood damage reduction programs
for the three planning objectives are anticipated. Flood plain manage-
ment measures will experience a minimal degree of effectiveness because
of the relatively low intensity of recorded flood damages and the
anticipated low future flood plain development. Flood plain management
is the only device considered necessary in the Penobscot Basin, and an
effectiveness factor of 20% is possible.

There are no existing flood damage reduction projects in Area 2.

WATER MANAGEMENT

Average annual runoff in Area 2 is approximately 9,650 m.g.d.
The existing minimum monthly flow (shortage index 0.01) is 3,220 m.g.d.
and the corresponding seven-day minimum is about 80% of this total, or
2,560 m.g.d. (See Appendix C). The addition of 8 m.g.d. as an allow-
ance for consumptive losses, results in an existing firm resource
available for use of 2,568 m.g.d., about 27% of the average runoff.

The practical limit of development within the Area, based on
potential yield of new surface storage and additional ground water,

would provide a maximum available resource of 5,814 m.g.d., or 60% of the average runoff. Potential sources which would develop the increase of 3,246 m.g.d., include major storage, accounting for 71% of the increase; upstream storage, 16%, and ground water development, 13%.

PROJECTED FLOOD DAMAGE
AREA 2
Penobscot River Basin

Emphasized Objective: ALL

Average Annual Damage - Million $ (6/70)

1.15

.60

Reduction from Management

Remaining Damage
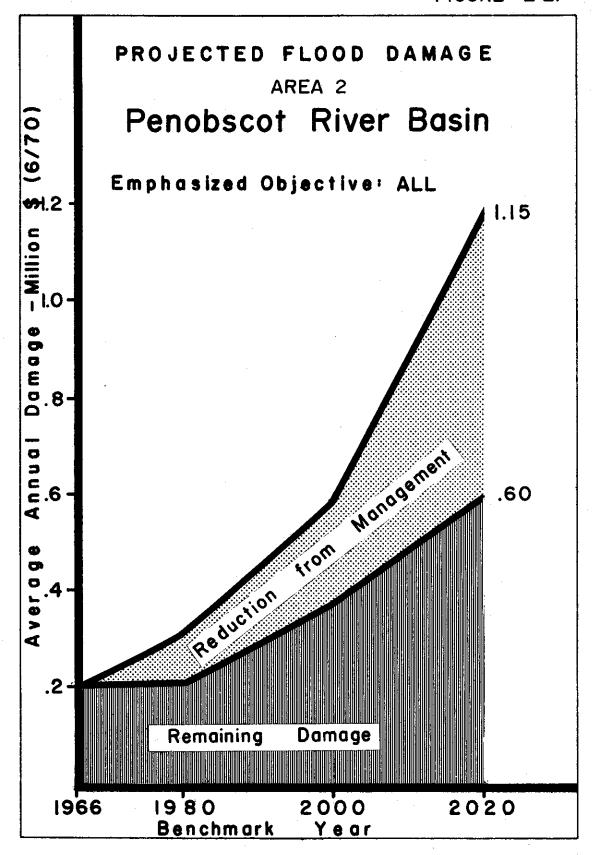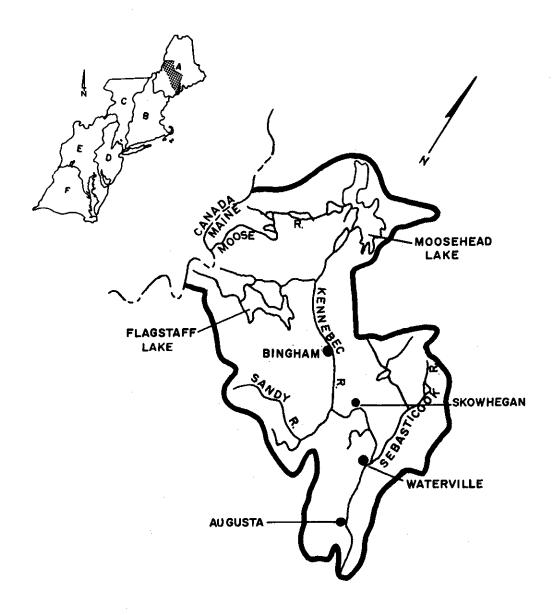
1966   1980   2000   2020
Benchmark   Year

FIGURE E-22

AREA 3   KENNEBEC RIVER BASIN

AREA 3. KENNEBEC RIVER BASIN

The Kennebec River Basin lies entirely in Maine and has a drainage area of about 5,870 square miles. Existing storage is about 1.4 million acre-feet, more than 80% of which is located above Bingham, Me., and includes 545,000 acre-feet in Moosehead Lake. The storage was developed almost exclusively for power and log-driving activities.

FLOOD DAMAGE REDUCTION

Area 3 flood damages are also relatively low and include only those caused by main stem and major tributary flooding, as hurricane, coastal stream and tidal flooding is insignificant. Despite anticipated new growth and the increasing value of existing structures in the flood plain, unrestrained future damages are not expected to be high. Lake, ponds and numerous dams and reservoirs built for other purposes cause considerable flood flow regulation.

The most severe flood of record occurred on March 19 and 20, 1936, and caused some $1.6 million in estimated damages. Average main stem record floods run about 10 times the average streamflow. Record flows on the more regulated tributaries range from 15 to 20 times the average streamflow, with flooding on the generally unregulated tributaries about 40 times average flows.

Structural measures are not considered desirable for flood damage reduction in the Kennebec Basin. Differences between programs for the three objectives were not distinguishable. Since the highest concentration of damageable assets is located near the State Capital in the lower basin, it is reasonable to assume a high level of effectiveness for flood plain management. The State is placing increased emphasis on non-structural devices in Area 3, and a 70% effectiveness factor is considered feasible.

There are no existing or potential flood damage reduction projects in Area 3.

WATER MANAGEMENT

Average annual runoff in Area 3 is approximately 6,500 m.g.d. The existing minimum monthly flow (shortage index 0.01) is 2,060 m.g.d., and the corresponding seven-day minimum is about 80% of this total, or 1,650 m.g.d. (See Appendix C). The addition of 7 m.g.d. as an allowance for consumptive losses results in an existing firm resource available for use of about 1,657 m.g.d., or 25% of the average runoff.

The practical limit of development within the Area, based on potential yield of new surface storage and additional ground water, would provide a maximum available resource of 2,816 m.g.d., or 43% of the average runoff. Potential sources which would develop the increase

of 1,159 m.g.d., include major storage, accounting for 33% of the increase; upstream storage, 41%, and ground water development, 26%.
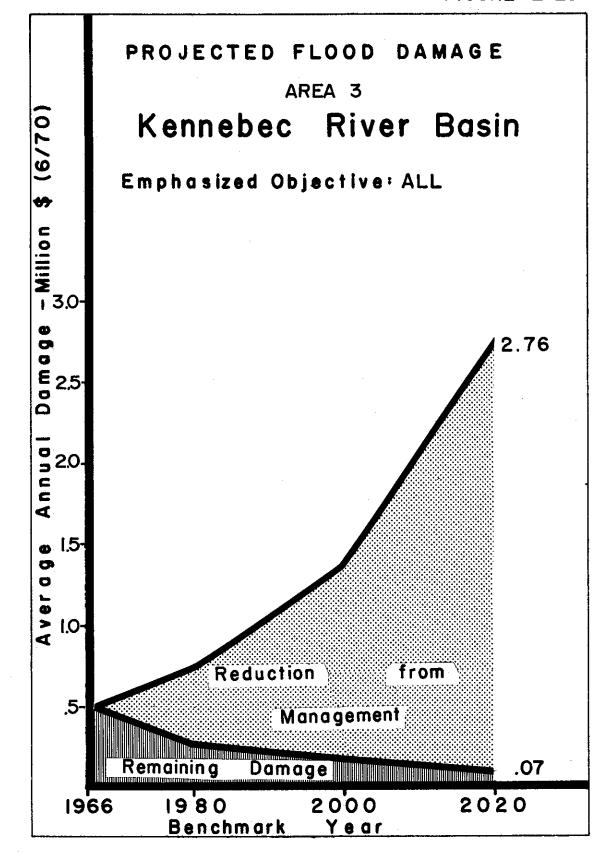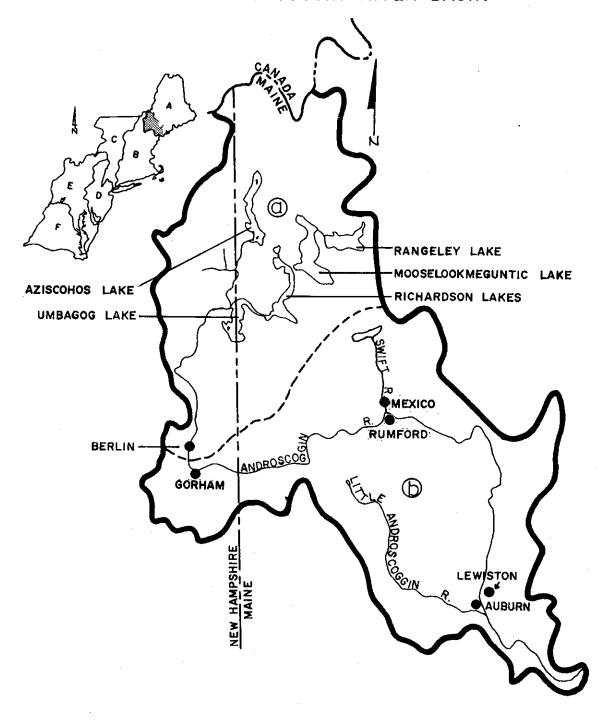
PROJECTED FLOOD DAMAGE

AREA 3

Kennebec River Basin

Emphasized Objective: ALL

FIGURE E-24

AREA 4   ANDROSCOGGIN RIVER BASIN

AREA 4. ANDROSCOGGIN RIVER BASIN

The Androscoggin River Basin has a drainage area of 3,450 square miles in portions of New Hampshire and Maine. Sub-area 4a, the area above Gorham, Me., contains about 38% of the total drainage area. There are approximately 750,000 acre-feet of usable storage in the basin, developed primarily for power and log-driving activities. More than 90% of this storage is in Sub-area 4a. It is noted that log-driving on the Androscoggin River ended in 1961.

FLOOD DAMAGE REDUCTION

Area 4, sustains the highest flood damages of all the major river basins in Sub-region A, a trend that will continue if flood plain development is not restrained. Flood losses are particularly heavy at Berlin, N. H., and Rumford, Mexico, Lewiston and Auburn, Me. There are no existing structural devices in the Area, although flood flows are subject to regulation from numerous lakes and ponds, and small dams and reservoirs constructed for other purposes.

The most severe flood of record in much of the Area was the flood of March 20, 1936, which caused estimated damages of $4.4 million. If it recurred under 1966 conditions, an estimated $18.7 million (June 1970 prices) in damages would result. Main stem record floods have ranged from 15 to 20 times the average streamflow.

There is one clear difference in flood damage reduction programs for the three planning objectives. Under the Regional Development and National Income objectives, the construction of Pontook Reservoir would be desirable, in combination with flood plain management measures. Under Environmental Quality, sole reliance on non-structural devices is most desirable, and flood plain management was the only flood damage reduction device considered.

Flood plain management is expected to have a better than average chance of success in Area 4, and a 50% effectiveness factor was used.

The status of Federal flood damage reduction projects in Area 4 is shown in Table E-13.

WATER MANAGEMENT

Average annual runoff in Area 4 is approximately 3,985 m.g.d. The existing minimum monthly flow (shortage index 0.01) is 1,400 m.g.d. and the corresponding seven-day minimum is about 80% of this or 1,115 m.g.d. (See Appendix C). The addition of 9 m.g.d. as an allowance for consumptive losses results in an existing firm resource available for use of about 1,124 m.g.d., or 28% of the average runoff.
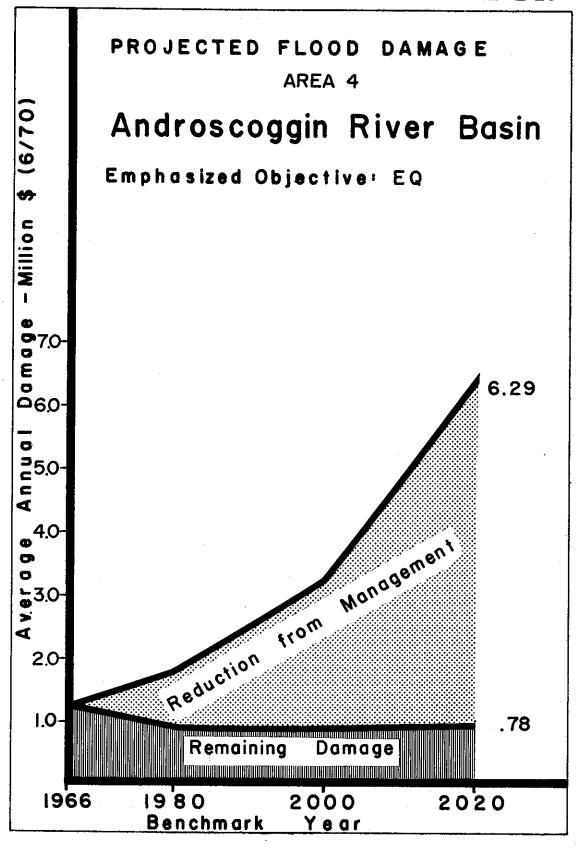
TABLE E-13

STATUS OF FLOOD DAMAGE REDUCTION PROJECTS - AREA 4

FLOOD STORAGE PROJECTS
(Map Symbol □)

UNDER CONSIDERATION (See Figure E-68)

Project	Map Number	Total Storage (Acre-feet)	Flood Control Storage (Acre-feet)	Estimated Total Cost ($1,000)	River
Pontook	4	238,000	58,000	97,000	Androscoggin

The practical limit of development within the Area, based on potential yield of new surface storage and additional ground water, would provide a maximum available resource of 2,442 m.g.d., or 61% of the average runoff. Potential sources which would develop the increase of 1,318 m.g.d., include major storage, accounting for 56% of the increase; upstream storage, 30%, and ground water development, 14%.

PROJECTED FLOOD DAMAGE

AREA 4

Androscoggin River Basin

Emphasized Objective: EQ

PROJECTED FLOOD DAMAGE

AREA 4

Androscoggin River Basin

Emphasized Objective: NI & RD

FIGURE E-27

AREA 5   MAINE COASTAL BASINS

AREA 5. MAINE COASTAL BASINS

Area 5 includes drainage from about 6,856 square miles in Maine and in Canada. Sub-area 5a, the St. Croix River Basin, includes 1,010 square miles in Maine and 1,635 square miles overall. Sub-area 5b, the coastal region between the St. Croix River and Cape Small, contains 5,221 square miles in Maine.

Area 5's total existing usable storage (in Maine) is about 880,000 acre-feet, almost 70% of which is located in Sub-area 5a. Most of this storage was developed for power and log-driving activities.

FLOOD DAMAGE REDUCTION

Flood damages in Area 5 are the lowest of all the Areas in Sub-region A, and include those caused by hurricane, coastal stream and tidal flooding, as well as flooding in the Narraguagus and St. Croix Basins. Under January 1966 conditions, average annual damages are distributed as follows: Coastal Streams - 71%; Coastal Tidal - 28%, and the Narraguagus River - 1%.

The Cherryfield Dam on the Narraguagus River is the only existing flood damage reduction structure in the Area, and it has reduced the basin's average annual damages, under 1966 conditions, by 99%. Remaining flood risk on the Narraguagus is negligible, barring future encroachment on the flood plain, and there is a high degree of regulation caused by small ponds and lakes. Ice jams frequently raise flood stages.

Record floods on major streams and rivers are about 10 times the average streamflows, while on some of the smaller tributaries record flows are about 15 times average flows. The flood of May 29 and 30, 1961, is generally one of the largest of record, although the flood of May 1, 1923, generated higher peaks on the Lower St. Croix. The 1923 flood caused estimated damages of $85,000 -- $50,000 on the St. Croix, and $35,000 along the Maine Coast.

In general, flooding is not a serious problem in this Area, because of its relatively flat topography and numerous lakes, ponds and swamps. However, prior to the construction of the Cherryfield Dam, flooding caused mainly by ice jams was a major problem on the Narraguagus.

Differences in flood damage reduction programs under the three objectives are negligible, and flood plain management measures have at least an average chance of reducing flood damages in Area 5. An effectiveness factor of 40% has been used.

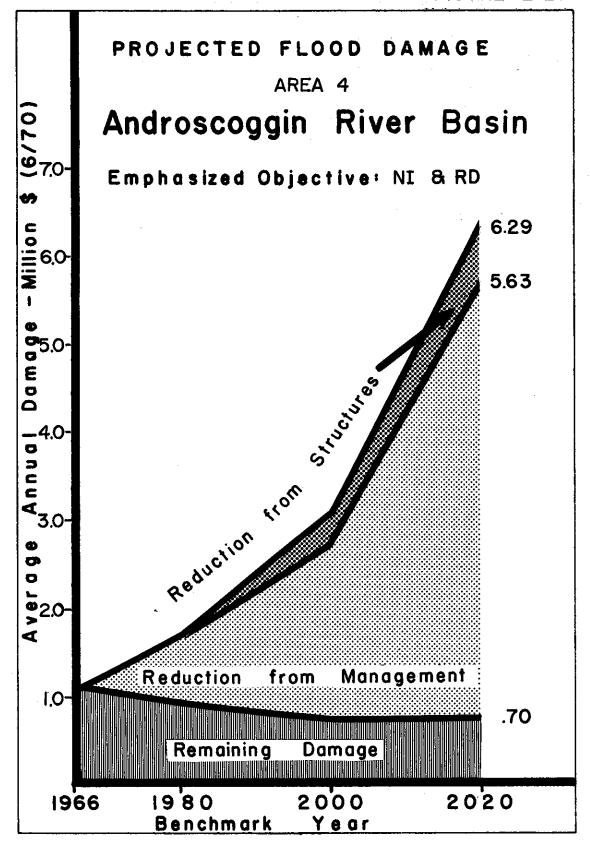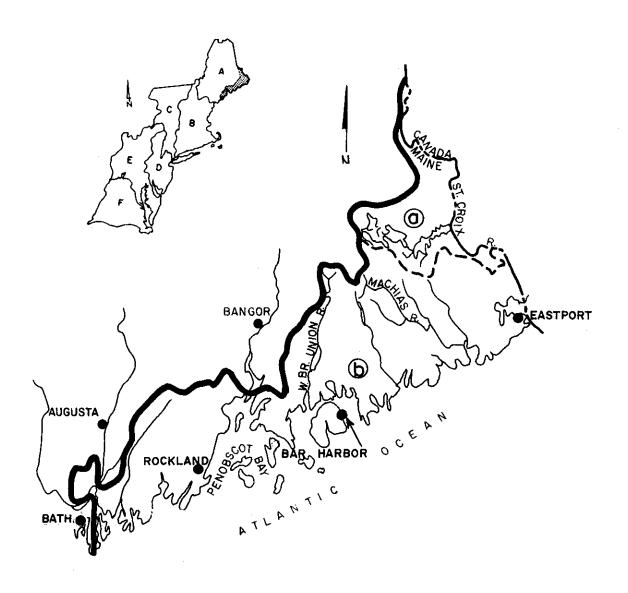The status of Federal flood damage reduction projects in Area 5 is shown in Table E-14.

TABLE E-14

STATUS OF FLOOD DAMAGE REDUCTION PROJECTS – AREA 5

LOCAL PROTECTION PROJECTS
(Map Symbol ▲)

EXISTING (See Figure E-67)

Project	Map Number	Total Cost ($1,000)	Year Completed	River
Cherryfield Dam	1	206.5	1961	Narraguagus

WATER MANAGEMENT
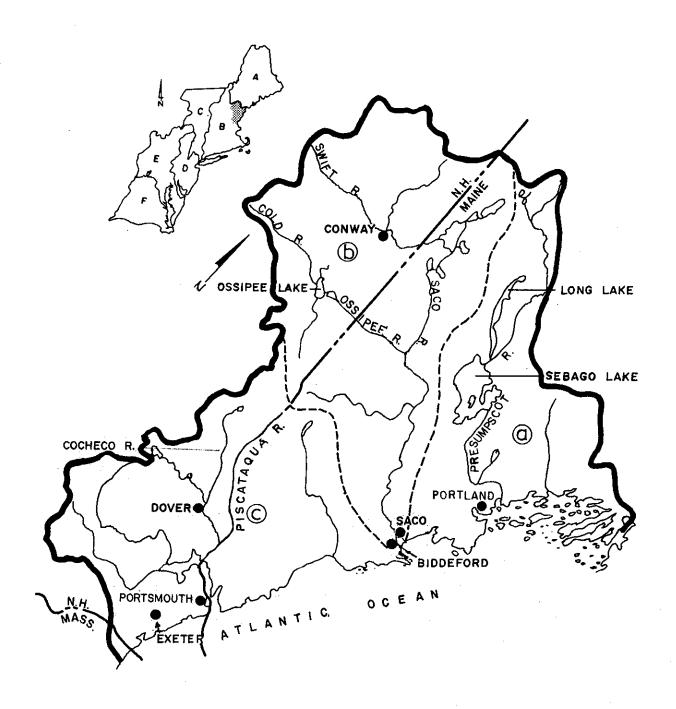
Average annual runoff in Area 5, including drainage from about 625 square miles in Canada, is approximately 7,520 m.g.d. The existing minimum monthly flow (shortage index 0.01) is 1,465 m.g.d., and the corresponding seven-day minimum is about 70% of this total or 1,020 m.g.d. (See Appendix C). The addition of 9 m.g.d. as an allowance for consumptive losses results in an existing firm resource available for use of about 1,029 m.g.d., or 14% of the average runoff.

The practical limit of development within the Area, based on potential yield of new surface storage and additional ground water, would provide a maximum available resource of 2,582 m.g.d., or 34% of the average runoff. Considering the U.S. portion only, the practical limit would be equivalent to about 36% of the average runoff. Potential sources which would develop the increase of 1,553 m.g.d., include major storage, accounting for 24% of the increase; upstream storage, 58%, and ground water development, 18%.

PROJECTED FLOOD DAMAGE

AREA 5

Maine Coastal Basins

Emphasized Objective: ALL

AREA 6   SOUTHERN MAINE AND COASTAL NEW HAMPSHIRE

AREA 6.   SOUTHERN MAINE AND COASTAL NEW HAMPSHIRE

The Southern Maine and Coastal New Hampshire Area has a total drainage area of about 4,208 square miles. The Presumpscot River Basin and adjoining coastal streams in Sub-area 6a account for 24% of the Area, the Saco River Basin, Sub-area 6b, 40%, and the Piscataqua River and Coastal streams of Sub-area 6c, the remainder.

Existing storage in Sub-area 6a amounts to about 290,000 acre-feet, of which nearly 80% is in Sebago Lake. The principal uses of storage in Sub-area 6a are for power, recreation and municipal supply. Sub-area 6b contains about 66,000 acre-feet of usable storage, used principally for power purposes, and the usable storage in Sub-area 6c is about 51,000 acre-feet, used mainly for power purposes.

FLOOD DAMAGE REDUCTION

Hurricane and coastal stream and tidal flooding are also reflected in flood damages in Area 6. Average annual flood damages, under January 1966 conditions, are distributed as follows: Saco River – 86%; Coastal Streams – 8%, and Coastal Tidal – 6%.

Existing and projected flood damages for the Area are minimal, and there is only one existing flood damage reduction structure, the Farmington Local Protection Project, which has reduced average annual damages along the Cocheco River by 39% (1966 conditions).

Flooding occurs almost annually along the Presumpscot, Saco and Piscataqua Rivers, concurrent with snowmelt and ice breakup. Ice jams frequently cause raised flood stages. Flood reduction and regulation are caused naturally by the generally flat topography of the Area, and its numerous lakes, ponds and swamps.

The flood of March 19-22, 1936, is generally the flood of record, causing estimated damages of $1.8 million in the Saco Basin.

In Sub-area 6a, record flood peaks have been about 10 times the average streamflows; while in Sub-area 6b, record floods have been about 45 times average flows, except in portions where natural regulation lowers this figure to about 20 times the average streamflow. Sub-area 6c has experienced record flooding of about 20 times average flows.

Differences between programs for the three objectives were not apparent in this Area. Low existing and projected damages should not require additional structural measures, and the existing structural devices have been considered as effective in containing future damage level projections. Flood plain management measures are considered to have a slightly less than average potential for success in this Area. A flood plain management effectiveness factor of 30% was used for all objectives.

The status of Federal flood damage reduction projects in Area 6 is shown in Table E-15.

TABLE E-15

STATUS OF FLOOD DAMAGE REDUCTION PROJECTS - AREA 6

LOCAL PROTECTION PROJECTS
(Map Symbol ▲)

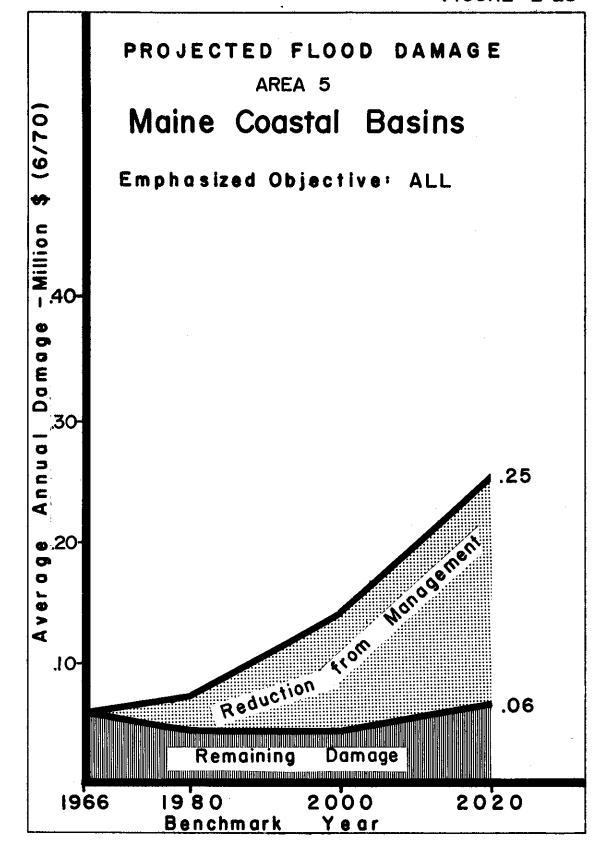EXISTING (See Figure E-67)

Project	Map Number	Total Cost ($1,000)	Year Completed	River
Farmington	2	191.7	1961	Cocheco

WATER MANAGEMENT

Average annual runoff in Area 6 is approximately 4,615 m.g.d. The existing minimum monthly flow (shortage index 0.01) is 655 m.g.d., and the corresponding seven-day minimum is about 77% of this total, or 578 m.g.d. (See Appendix C). The addition of 18 m.g.d. as an allowance for consumptive losses, results in an existing firm resource available for use of about 596 m.g.d., or 13% of the average runoff.

The practical limit of development within the Area, based on potential yield of new surface storage and additional ground water, would provide a maximum available resource of 1,889 m.g.d., or 41% of the average runoff. Potential sources which would develop the increase of 1,293 m.g.d., include major storage, accounting for 33% of the increase; upstream storage, 52%, and ground water development, 15%.

PROJECTED FLOOD DAMAGE
AREA 6
Southern Maine
and Coastal New Hampshire
Emphasized Objective: ALL

Average Annual Damage – Million $ (6/70)

4.0

3.0

2.0

1.0

3.15

1.08

Reduction from Management

Remaining Damage
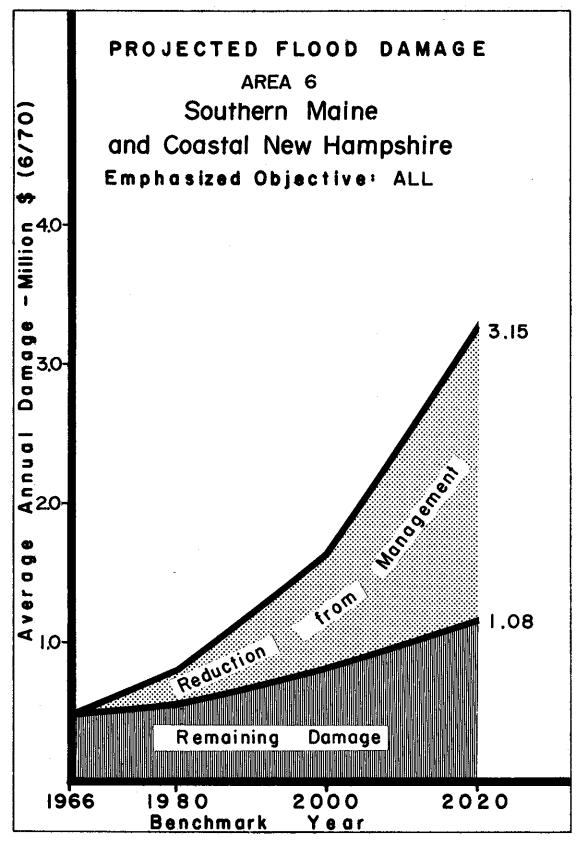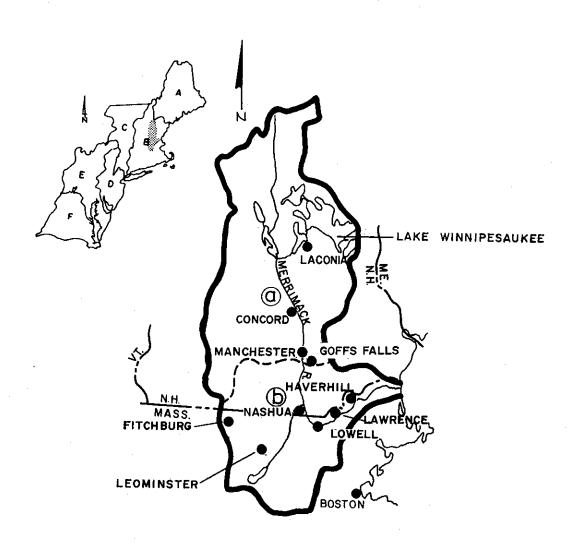
1966   1980   2000   2020
Benchmark   Year

FIGURE E-31

AREA 7 MERRIMACK RIVER BASIN

AREA 7. MERRIMACK RIVER BASIN

The Merrimack River Basin has a drainage area of about 5,050 square miles in New Hampshire and Massachusetts. Sub-area 7a, the area above Goffs Falls, N.H., contains about 60% of the drainage area. Existing usable storage amounts to about 910,000 acre-feet, with approximately 35% developed for power and recreation, 23% for municipal supply, and about 42% for flood control, with recreational use included in most places. About 80% of the total storage is in Sub-area 7a.

FLOOD DAMAGE REDUCTION

Merrimack River main stem flood damages are the only damages considered in this summary because of the relative insignificance of damages caused by coastal-related flooding in Area 7. Average annual flood damages, under January 1966 conditions, are distributed as follows: Merrimack River – 59%; Nashua River – 22%; Pemigewasset River – 6%; Winnepesaukee River – 3%; Contoocook River – 6%; Piscataugua River – 2%; Shawsheen River – 1%; and the Sudbury River – 1%.

Although total flood damages for the Merrimack Basin are low compared to other Areas in Sub-region B, flooding is a particularly serious hazard, especially in Sub-area 7b, because of the population concentration in the lower Merrimack Basin and resultant heavy flood plain development.

Flooding occurs annually with the heavy spring rainfall and seasonal snowmelt. Existing projects have reduced average annual flood damages (1966 conditions) in Area 7 by 55%.

The most severe flood of record occurred on March 19 and 20, 1936. This flood caused an estimated $35 million in damages. Stream-flows in the Area are regulated by numerous power reservoirs, natural lakes, and flood damage reduction projects. Record floods on the main stem have ranged from 20 to 30 times the average streamflow. Record floods on unregulated tributaries have ranged from 50 to 60 times average flows.

Differences in flood damage reduction programs for the three planning objectives are not distinguishable in the Merrimack Basin. Some authorized projects are considered effective in reducing damages in future bench mark years, as follows: 1980 --Nookagee Lake and Whitmanville Lake, and the Saxonville local protection project; 2000 -- the Monoosnoc Lake and Phillips Lake, and local protection projects on Baker Brook, Monoosnoc Lake and the North Nashua River. It is also concluded that flood plain management measures have a better than average chance of success in Area 7, with an effectiveness factor of 50%.

The status of Federal flood damage reduction projects in Area

7 is shown in Table E-16.

WATER MANAGEMENT

Average annual runoff in Area 7 is approximately 5,380 m.g.d. The existing minimum monthly flow (shortage index 0.01) is 880 m.g.d., and the corresponding seven-day minimum is about 60% of this total, or 530 m.g.d. (See Appendix C). The addition of 45 m.g.d. as an allowance for consumptive losses and 95 m.g.d. developed for export to Area 9, results in an existing firm resource available for use of about 670 m.g.d., or 12% of the average runoff.

The practical limit of development within the Area, based on potential yield of new surface storage and additional ground water, would provide a maximum available resource of 2,894 m.g.d., or 54% of the average runoff. Potential sources which would develop the increase of 2,224 m.g.d., include major storage, accounting for 56% of the increase; upstream storage, 32%, and ground water development, 12%.

TABLE E-16
STATUS OF FLOOD DAMAGE REDUCTION PROJECTS — AREA 7

LOCAL PROTECTION PROJECTS
(Map Symbol ▲)

EXISTING (See Figure E-67)

Project	Map Number	Total Cost ($1,000)	Year Completed	River
Fitchburg	3	1,370.0	1938	North Nashua
Haverhill	4	1,863.0	1938	Merrimack-Little
Lincoln	5	120.0	1960	East Branch Pemigewasset
Lowell	6	1,375.0	1944	Merrimack
Nashua	7	273.0	1948	Nashua-Merrimack

AUTHORIZED (See Figure E-68)

Project	Map Number	Estimated Total Cost ($1,000)	Year Authorized	River
Baker Brook (UD)	1	1,315.1	1966	Baker Brook
Monoosnoc Brook (D)	2	431.2	1966	Monoosnoc Brook
North Nashua (NF)	3	1,040.0	1966	North Nashua
Saxonville (UD)	4	2,200.0	1966	Sudbury

INACTIVE (See Figure E-68)

Project	Map Number	Estimated Total Cost ($1,000)	Year Authorized	River
Lawrence and North Andover	1	3,662.6	1938	Merrimack-Shawsheen

UD - Under Design
NF - Not Funded
D - Deferred

STATUS OF FLOOD DAMAGE REDUCTION PROJECTS — AREA 7

FLOOD STORAGE PROJECTS
(Map Symbol □)

EXISTING (See Figure E-67)

Project	Map Number	Total Storage (Acre-feet)	Flood Control Storage (Acre-feet)	Total Cost ($1,000)	Year Completed	River
Blackwater	2	46,000	46,000	1,319.7	1941	Blackwater
Edward McDowell	1	13,000	12,800	2,014.3	1950	Nubanusit Brook
Franklin Falls	3	154,000	150,600	7,950.0	1943	Pemigewasset
Hopkinton-Everett	4	157,300	155,600	21,870.0	1965	Contoocook-Piscataquog

AUTHORIZED (See Figure E-68)

Project	Map Number	Total Storage (Acre-feet)	Flood Control Storage (Acre-feet)	Estimated Total Cost ($1,000)	Year Authorized	River
Monoosnoc Lake (D)	5	2,000	800	3,800.0	1966	South Branch Monoosnoc Brook
Nookagee (UD)	3	8,400	4,700	8,000.0	1966	Phillips Brook
Phillips (NF)	4	1,600	1,600	3,400.0	1966	Phillips Brook
Whitmanville (UD)	2	7,850	6,700	5,800.0	1966	Whitman

INACTIVE (See Figure E-68)

Project	Map Number	Total Storage (Acre-feet)	Flood Control Storage (Acre-feet)	Estimated Total Cost ($1,000)	Year Authorized	River
Mountain Brook	1	5,300	5,300	3,062.1	1936	Mountain Brook

UD - Under Design
NF - Not Funded
D - Deferred

PROJECTED FLOOD DAMAGE
AREA 7
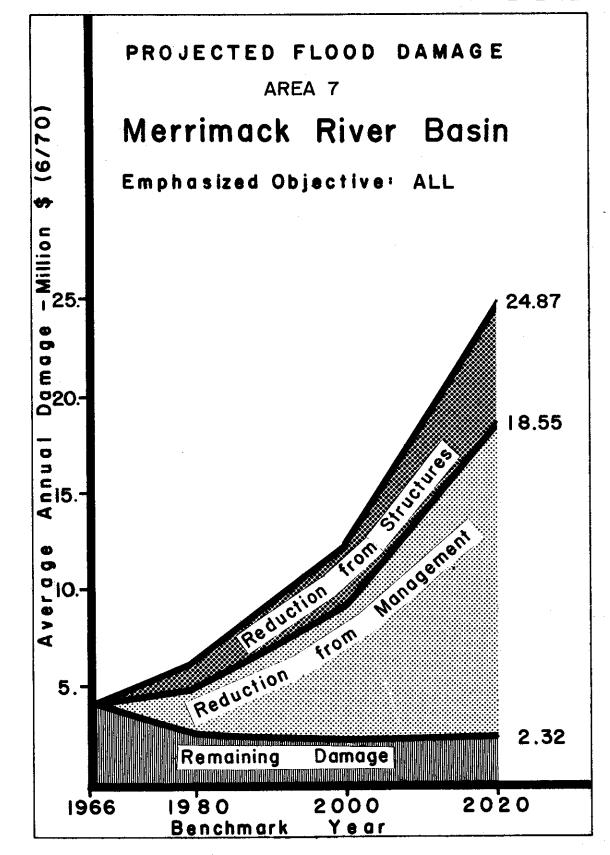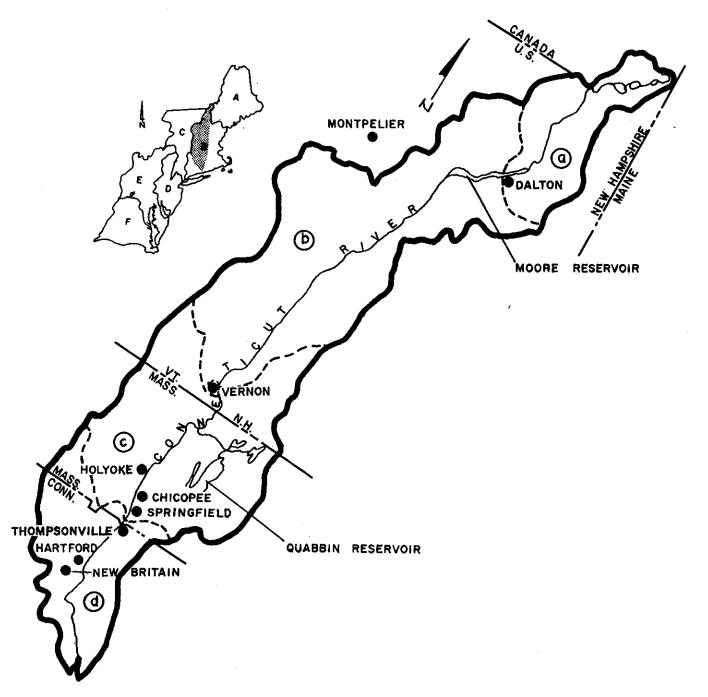Merrimack River Basin
Emphasized Objective: ALL

FIGURE E-33

AREA 8   CONNECTICUT RIVER BASIN

AREA 8.   CONNECTICUT RIVER BASIN

The Connecticut River Basin has a drainage area of 11,250 square miles in portions of Canada, Vermont, New Hampshire, Massachusetts and Connecticut.   Sub-area 8a, above Dalton, N.H., contains about 13.5% of the entire Area, Sub-area 8b, above Vernon, Vt., 42.5%; Sub-area 8c, above Thompsonville, Conn., about 30%; and Sub-area 8d, the remaining drainage area, 14%.

The total usable storage capacity is nearly 2.6 million acre-feet.   Quabbin Reservoir, in Sub-area 8c, has a storage capacity of 1.24 million acre-feet, used principally for municipal supply.   A breakdown of Area 8's total storage shows some 18% being used for flood control, at 26% for power, and 56% for water supply purposes.

FLOOD DAMAGE REDUCTION

Area 8 flood damages include main stem and major tributary flooding only.   Average annual damages under January 1966 conditions, are distributed as follows: Sub-area 8a - 4%; Sub-area 8b - 17%; Sub-area 8c - 31%, and Sub-area 8d - 48%.

Flooding in the Connecticut Basin has been a recurring problem, with the potential to produce devastating floods far in excess of any recorded so far.   Such flows would overtop many existing flood protection structures.   The high degree of existing control is reflected by the fact that average annual damages, under 1966 conditions, have been reduced about 74% by the projects.

Floods usually occur in the spring with the seasonal snowmelt and ice breakup.   Major floods have occurred in November 1927, March 1936, September 1938 and August 1955.   The 1936 flood caused damages estimated at $66.4 million, and would cause an estimated $415.7 million (June 1970 prices) in damages if it recurred under 1966 conditions. Main stem record floods have ranged from 15 to 20 times the average streamflow, and record floods on major unregulated tributaries are about 50 times average flows, with some floods ranging up to 100 times the average.

There are significant differences in flood damage reduction programs for the three planning objectives in Area 8.   The Environmental Quality objective can best be met by utilizing flood plain management as the sole flood damage reduction device.   The National Income and Regional Development objectives can best be satisfied by a combination of structural devices and flood plain management.   It is recognized that the States, especially Connecticut, are placing increased emphasis on flood plain management.   The basin was evaluated as having an average chance of success with flood plain management measures, and a 40% effectiveness factor was used.

The White River Local Protection Project, completed in 1970, was considered effective in 1966. Under the National Income and Regional Development objectives, the following projects were considered effective in 1980: Bethlehem Junction, Claremont, Beaver Brook, Honey Hill, Victory, Gaysville and Meadow Reservoirs; additional storage at the existing Knightville Reservoir, and local protection projects at Lancaster, N.H., St. Johnsbury, Vt., Westfield, Mass., and on the Park River at Hartford, Conn.

The status of Federal flood damage reduction projects in Area 8 is shown in Table E-17.

WATER MANAGEMENT

Average annual runoff in Area 8, including contributing drainage from 114 square miles in Canada, is approximately 12,230 m.g.d. The existing minimum monthly flow (shortage index 0.01) is 2,400 m.g.d., and the corresponding seven-day minimum is about 60% of this total, or 1,425 m.g.d. (See Appendix C). The addition of 77 m.g.d. as an allowance for consumptive losses, and 195 m.g.d. developed for export to Area 9 through Area 7, results in an existing firm resource available for use of about 1,697 m.g.d., or 14% of the average runoff.

The practical limit of development within the Area, based on potential yield of new surface storage and additional ground water, would provide a maximum available resource of 5,159 m.g.d., or 42% of the average runoff. Potential sources which would develop the increase of 3,462 m.g.d., include major storage, accounting for 51% of the increase; upstream storage, 33%, and ground water development, 16%.

TABLE E-17
STATUS OF FLOOD DAMAGE REDUCTION PROJECTS — AREA 8

LOCAL PROTECTION PROJECTS
(Map Symbol ▲)

EXISTING (See Figure E-67)

Project	Map Number	Total Cost ($1,000)	Year Completed	River
Chicopee	8	1,684.0	1941	Connecticut-Chicopee
Chicopee Falls	9	2,655.0	1965	Chicopee
East Hartford	10	2,405.4	1943	Connecticut-Hockanum
Gardner	11	528.9	1965	Mahoney-Greenwood Brooks
Hartford, Conn.	12	10,621.2	1944	Connecticut-Park, Gully-Folly Brooks
Holyoke-Springdale	13	4,325.0	1940	Connecticut
Huntington	14	4.0	1959	West Branch Westfield
Keene	15	44.1	1954	Ashuelot
Northampton	16	1,110.0	1941	Connecticut-Mill
Springfield	17	1,209.4	1948	Connecticut-Mill
Three Rivers	18	2,277.2	1966	Chicopee-Ware-Quaboag
Ware	19	485.0	1959	Ware
Weston	20	14.8	1957	West
West Springfield-Riverdale	21	2,797.0	1953	Connecticut-Westfield
West Warren	22	430.2	1963	Quaboag
White River	94	264.0	1970	White
Winsted	23	275.5	1951	Mad

AUTHORIZED (See Figure E-68)

Project	Map Number	Estimated Total Cost ($1,000)	Year Authorized	River
Park	5	42,100.0	1958	Park

INACTIVE (See Figure E-68)

Project	Map Number	Estimated Total Cost ($1,000)	Year Authorized	River
Ludlow	2	12,404.8	1958	Black-Jewell Brook
St. Johnsbury	7	980.0	1967	Passumpsic-Sleepers

UNDER CONSIDERATION (See Figure E-68)

Project	Map Number	Estimated Total Cost ($1,000)	River
Lancaster	1	524.0	Israel
Westfield	2	11,200.0	Westfield

FLOOD STORAGE PROJECTS
(Map Symbol ▣)

EXISTING (See Figure E-67)

Project	Map Number	Total Storage (Acre-feet)	Flood Control Storage (Acre-feet)	Total Cost ($1,000)	Year Completed	River
Ball Mountain	5	54,600	52,350	10,535.2	1961	West
Barre Falls	6	24,000	24,000	1,967.8	1958	Ware
Birch Hill	7	49,900	49,900	4,547.7	1942	Millers
Colebrook River	8	97,700	50,200	14,100.0	1969	West Branch Farmington
Conant Brook	9	3,740	3,740	2,949.7	1966	Conant Brook
Knightville	10	49,000	49,000	3,220.4	1941	Westfield
Littleville	11	32,400	23,000	7,013.0	1965	Middle Branch Westfield
Mad River	12	9,700	9,510	4,770.8	1963	Mad
North Hartland	13	71,800	68,750	7,101.5	1961	Ottauquechee
North Springfield	14	50,500	48,500	6,822.7	1960	Black
Otter Brook	15	18,320	17,600	4,260.0	1958	Otter Brook
Sucker Brook	16	1,480	1,480	2,414.0	1969	Still
Surrey Mountain	17	33,000	31,680	2,600.0	1942	Ashuelot
Townshend	18	33,600	32,800	7,288.2	1961	West
Tully	19	22,000	20,500	1,551.6	1949	Tully
Union Village	20	38,000	38,000	4,210.0	1950	Ompompanoosuc

AUTHORIZED (See Figure E-68)

Project	Map Number	Total Storage (Acre-feet)	Flood Control Storage (Acre-feet)	Estimated Total Cost ($1,000)	Year Authorized	River
Beaver Brook	6	5,750	2,750	1,660.0	1968	Beaver Brook
The Island (D)	7	19,400	19,400	7,919.4	1954	West
Victory	10	76,000	24,000	6,600.0	1941	Moose

INACTIVE (See Figure E-68)

Project	Map Number	Total Storage (Acre-feet)	Flood Control Storage (Acre-feet)	Estimated Total Cost ($1,000)	Year Authorized	River
Brockway	2	37,700	37,700	23,327.2	1941	North Branch Williams
Cambridgeport	3	21,600	21,600	11,271.2	1941	Saxtons
Claremont	7	78,400	78,400	20,910.0	1938	Sugar
Gaysville	6	82,500	73,700	31,600.0	1941	White
Honey Hill	9	26,200	26,200	11,100.0	1941	South Branch Ashuelot
Ludlow	4	23,900	23,900	12,404.8	1936	Black
South Tunbridge	5	32,600	32,600	11,859.8	1938	First Branch White
West Canaan	8	34,100	34,100	19,751.8	1938	Mascoma
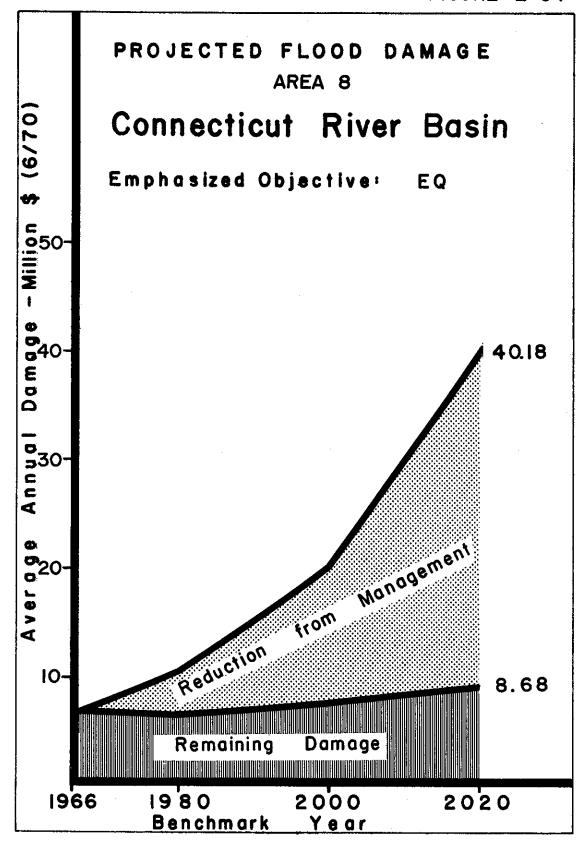
UNDER CONSIDERATION (See Figure E-68)

Project	Map Number	Total Storage (Acre-feet)	Flood Control Storage (Acre-feet)	Estimated Total Cost ($1,000)	River
Bethlehem Junction	1	55,600	29,600	16,000.0	Amonoosuc
Knightville Modification	2	52,900	52,900	4,400.0	Westfield
Meadow	3	160,400	160,400	41,400.0	Deerfield

D - Deferred

PROJECTED FLOOD DAMAGE
AREA 8
Connecticut River Basin
Emphasized Objective: EQ

PROJECTED FLOOD DAMAGE

AREA 8

Connecticut River Basin

Emphasized Objective: NI & RD

FIGURE E-36

AREA 9 SOUTHEASTERN NEW ENGLAND

AREA 9.   SOUTHEASTERN NEW ENGLAND

The Southeastern New England Area drainage basins include the Massachusetts Coastal Area, Sub-area 9a; and the Pawcatuck River and Narragansett Bay drainage basins and the remainder of the Rhode Island Coastal Area, comprising Sub-area 9b. Of Area 9's total drainage of 4,576 square miles, Sub-area 9a contains about 51%.

Existing usable storage capacity in Sub-area 9a is minimal and has no significant effect on streamflow. The largest reservoir in Sub-area 9b is the Scituate Reservoir in the Pawtuxet River Basin, with a capacity of 112,000 acre-feet, used for the municipal water supply of Providence, R.I., and surrounding areas.

FLOOD DAMAGE REDUCTION

Area 9 flood damages reflect both tidal and coastal stream flooding. Average annual flood damages, under January 1966 conditions, are distributed as follows: Massachusetts Coast Tidal - 26%; Massachusetts Coastal Streams - 19%; Rhode Island Coast Tidal - 43%; Rhode Island Coastal Streams - 1%, and the Blackstone River - 11%.

The heaviest flood damages in this Area have occurred from hurricane tidal flooding. Hurricane Diane, which hit the Area on August 17-20, 1955, caused generally the most severe flood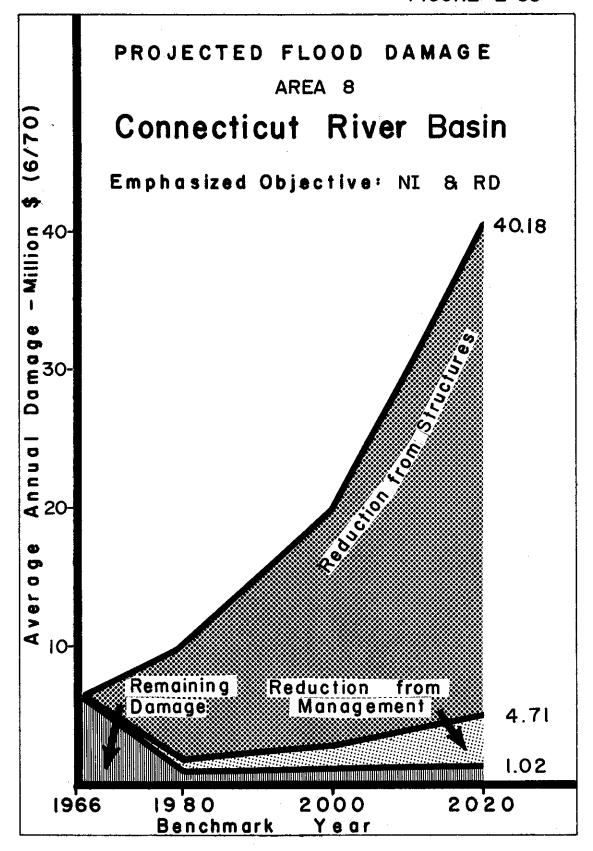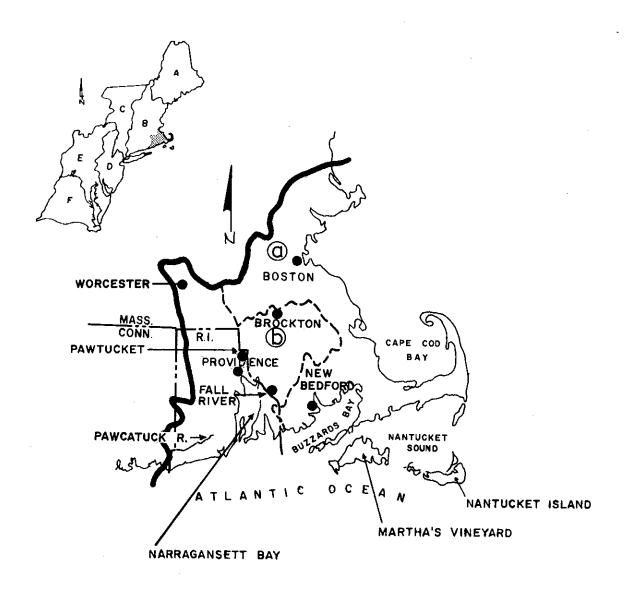ing. Along the Rhode Island Coast and in the Narragansett Basin, this storm caused estimated flood damages of $70 million. The flood of March 18-22, 1936, caused about $341,000 in flood damages, the highest along the Massachusetts Coast.

Existing and projected flood damages for Area 9 are the highest in Sub-region B. Existing flood control structures reduced damages by some 40% under 1966 conditions. Record flood flows on most coastal streams are about 10 times the average streamflows, with record flows on the Blackstone River ranging up to 70 times the average.

Differences in programs for the three objectives are minimal in this Area. Flood plain management, for all objectives, has an effectiveness factor of 50%. Public attitudes and the general topography of the Area lend support to a forecast for better than average success for flood plain management measures.

In consideration of all objectives, Charles River Dam improvements were assumed effective in 1980, and the Westerly Hurricane Protection Project was assumed effective in 2000. Under the National Income and Regional Development objectives, hurricane protection projects at Narragansett Pier, Point Judith and Wareham-Marion were assumed operational in 2000.

The status of Federal flood damage reduction projects in Area

9 is shown in Table E-18.

WATER MANAGEMENT

       Area 9's average annual runoff is approximately 5,280 m.g.d. The existing minimum monthly flow (shortage index 0.01) is 1,150 m.g.d., and the corresponding seven-day minimum is about 60% of this total, or 690 m.g.d. (See Appendix C). The addition of 110 m.g.d. as an allowance for the portion of the consumption losses reflected in the stream-flow measurements, results in an existing firm resource available for use of about 800 m.g.d., or 15% of the average runnoff. This does not include about 290 m.g.d., which can be imported into the Area by the Metropolitan District Commission.

       The practical limit of development within the Area, based on potential yield of new surface storage and additional ground water, would provide a maximum available resource of 1,832 m.g.d., or 35% of the average runoff. Potential sources which would develop the increase of 1,032 m.g.d., include major storage, accounting for 8% of the increase; upstream storage, 20%, and ground water development, 72%.

TABLE E-18
STATUS OF FLOOD DAMAGE REDUCTION PROJECTS – AREA 9

LOCAL PROTECTION PROJECTS
(Map Symbol ▲)

EXISTING (See Figure E-67)

Project	Map Number	Total Cost ($1,000)	Year Completed	River
Canton	24	272.7	1963	Neponset
Fox Point Barrier	25	15,850.0	1966	Providence
Lower Woonsocket	26	9,150.0	1966	Blackstone
New Bedford, Fairhaven and Acushnet	30	18,600.0	1966	Buzzards Bay
Pawcatuck	27	920.4	1963	Pawcatuck
Woonsocket	28	4,809.0	1959	Blackstone
Worcester Diversion	29	5,960.5	1960	Blackstone

AUTHORIZED (See Figure E-68)

Project	Map Number	Estimated Total Cost ($1,000)	Year Authorized	River
Charles River Dam	34	31,800.0	1968	Charles
Westerly	9	7,440.0	1965	Atlantic Ocean
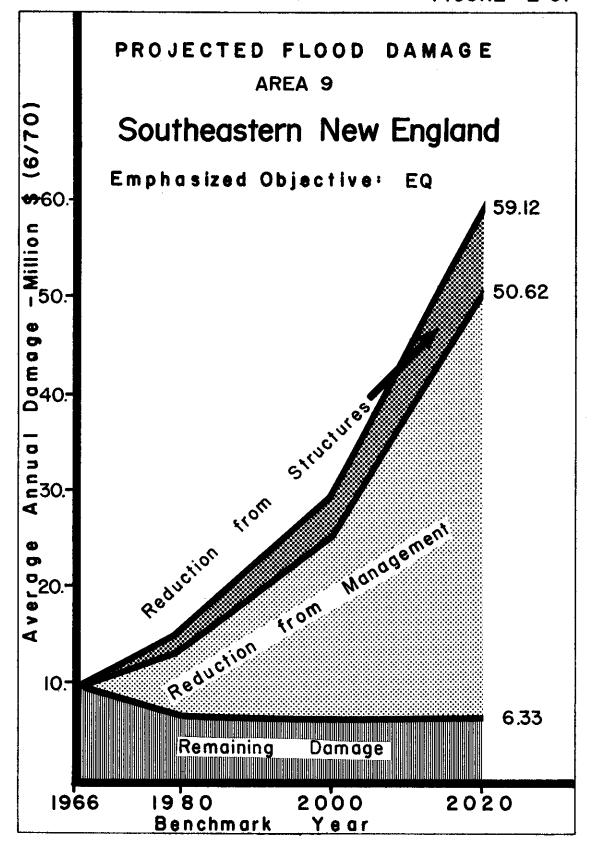
INACTIVE (See Figure E-68)

Project	Map Number	Estimated Total Cost ($1,000)	Year Authorized	River
Narragansett Pier	10	3,509.8	1962	Narragansett Bay
Point Judith	3	9,971.2	1962	Block Island
Wareham-Marion	11	9,314.4	1962	Weweantic-Wareham-Onset Bay

FLOOD STORAGE PROJECTS
(Map Symbol ▫)

EXISTING (See Figure E-67)

Project	Map Number	Total Storage (Acre-feet)	Flood Control Storage (Acre-feet)	Total Cost ($1,000)	Year Completed	River
West Hill	21	12,440	12,440	2,380.0	1961	West

PROJECTED FLOOD DAMAGE

AREA 9

Southeastern New England

Emphasized Objective: EQ

PROJECTED FLOOD DAMAGE

AREA 9

Southeastern New England

Emphasized Objective: NE & RD

FIGURE E-39

AREA 10 THAMES AND HOUSATONIC RIVER BASINS

AREA 10. THAMES AND HOUSATONIC RIVER BASINS

Area 10 has been divided into the Thames River Basin and the Connecticut Coastal Streams east of the Connecticut River Basin, comprising Sub-area 10a; and Sub-area 10b, which includes the Housatonic River Basin and adjacent Connecticut Coastal Streams. The Area drains some 4,555 square miles, with about 37% in Sub-area 10a.

Existing usable storage capacity in the Area totals about 417,000 acre-feet. The Thames Basin contains about 33% of the existing storage used primarily for flood control. Another 54% of the total storage is in the Housatonic Basin, with major development for power, recreation and flood control, and some storage for municipal supply.

FLOOD DAMAGE REDUCTION

Area 10 main stem flooding also includes tidal and coastal stream flooding. Average annual flood damages under January 1966 conditions, are distributed as follows: Thames River - 11%; Housatonic River - 11%; Coastal Streams - 7%, and Tidal Flooding - 71%.

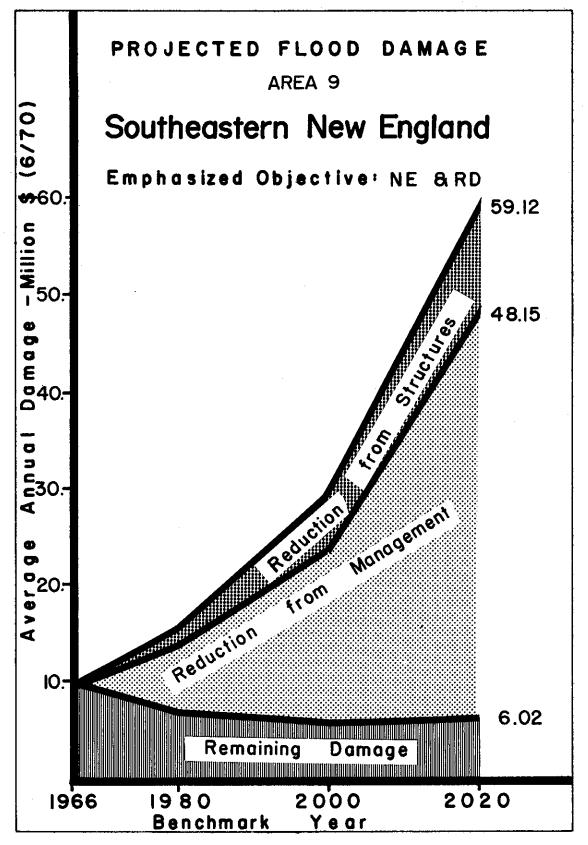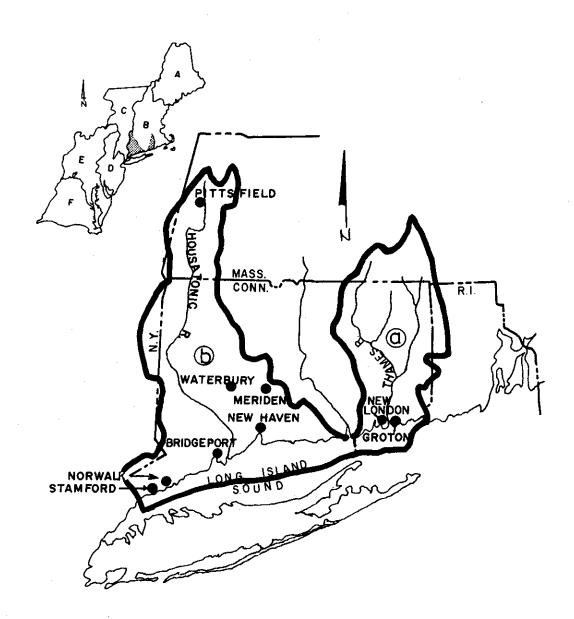Present flood characteristics reflect the high degree of existing control and regulation. Existing structures reduce average annual damages, under 1966 conditions, by 57%.

The most severe flood of record was caused by the storm of August 19, 1955, when 12.12 inches of precipitation were recorded at Hartford, Conn. That flood caused estimated damages of some $362.9 million -- $61.7 million in the Thames Basin, $258 million in the Housatonic Basin, $15 million along the Connecticut Coast, and $28.2 million on minor tributaries.

The record floods of the past have generally peaked at about 50% of the peak flow generated by the 1955 storm, which generated flows about 20 times the average on major tributaries, and about 30 times average flows on the lower main stems.

All projects constructed prior to January 1966 were considered effective in reducing flood damages. Some projects, either already built or in the pre-construction or authorized stages, were considered effective in the base year 1966. They are Trumbull Pond, Black Rock, Hancock Brook and Hop Brook, all reservoir projects; and local protection projects at Stamford and Ansonia-Derby.

Authorized local protection projects are Derby, Danbury, Stratford and New London were considered as constructed and effective for all objectives in 1980. The Mystic Local Protection Project has been considered effective in 2000.

The most significant need for flood damage reduction beyond

2000 will be in the tidal area, and public attitudes are generally opposed to the construction of high or visually unaesthetic devices along the coast. However, it is felt that some small projects and multiple-purpose beach erosion control may be justified.

No discernible differences in flood damage reduction programs for the three objectives were found in this Area, although increased attention to flood plain management is considered compatible with Environmental Quality. Flood plain management appears to have at least as good a chance, and a 40% effectiveness factor has been used in Area 10.

The status of Federal flood damage reduction projects in Area 10 is shown in Table E-19.

WATER MANAGEMENT

Average annual runoff in Area 10 is approximately 4,870 m.g.d. The existing minimum monthly flow (shortage index 0.01) is 520 m.g.d., and the corresponding seven-day minimum is about 60% of this total, or 312 m.g.d. (See Appendix C). The addition of 82 m.g.d. as an allowance for consumptive losses results in an existing firm resource available for use of about 394 m.g.d., or 8% of the average runoff.

The practical limit of development within the Area, based on potential yield of new surface storage and additional ground water, would provide a maximum available resource of 1,373 m.g.d., or 28% of the average runoff. Potential sources which would develop the increase of 979 m.g.d., include major storage, accounting for 55% of the increase; upstream storage, 22%, and ground water development, 23%.

TABLE E-19
STATUS OF FLOOD DAMAGE REDUCTION PROJECTS – AREA 10

LOCAL PROTECTION PROJECTS
(Map Symbol ▲)

EXISTING (See Figure E-67)

Project	Map Number	Total Cost ($1,000)	Year Completed	River
Norwich	31	1,282.0	1958	Shetucket
East Torrington	35	540.5	1958	Naugatuck
Norwalk	32	55.0	1951	Norwalk
Pemberwick	33	407.0	1960	Byram
Stamford	34	11,700.0	1969	Long Island Sound
Waterbury-Watertown	37	278.3	1961	Naugatuck
West Torrington	36	370.1	1960	Naugatuck

AUTHORIZED (See Figure E-68)

Project	Map Number	Estimated Total Cost ($1,000)	Year Authorized	River
New London (U.D.-F)	13	11,600.0	1962	Long Island Sound
Ansonia-Derby (U.C.)	35	19,050.0	1962	Naugatuck
Danbury (U.D.-F)	14	8,340.0	1965	Still
Derby (U.C.)	15	8,230.0	1965	Housatonic-Haugatuck
Stratford (U.D.)	16	18,000.0	1965	Long Island Sound

INACTIVE (See Figure E-68)

Project	Map Number	Estimated Total Cost ($1,000)	Year Authorized	River
Mystic	4	7,712.1	1962	Mystic
Westport	5	659.7	1962	Long Island Sound

UD – Under Design
F – Funded
UC – Under Construction

FLOOD STORAGE PROJECTS
(Map Symbol □)

EXISTING (See Figure E-67)

Project	Map Number	Total Storage (Acre-feet)	Flood Control Storage (Acre-feet)	Total Cost ($1,000)	Year Completed	River
Buffumville	22	12,700	11,300	3,200.0	1958	Little
East Brimfield	23	32,200	28,800	7,310.0	1960	Quinebaug
Hodges Village	24	13,250	12,800	4,421.0	1959	French
Mansfield-Hollow	25	52,000	52,000	6,550.0	1952	Natchaug
West Thompson	26	26,800	25,600	6,870.0	1965	Quinebaug
Westville	27	11,100	11,100	5,690.0	1962	Quinebaug
Black Rock	29	8,700	8,430	8,245.0	1970	Branch Brook
East Branch	30	4,350	4,350	2,723.8	1964	Naugatuck
Hall Meadow Brook	31	8,620	8,620	3,142.4	1962	Hall Meadow Brook
Hancock Brook	32	4,030	4,030	4,123.0	1966	Hancock Brook
Hop Brook	33	6,970	6,850	5,532.8	1965	Hop Brook
Northfield Brook	34	2,430	2,350	2,831.0	1965	Northfield Brook
Thomaston	35	42,000	42,000	14,280.0	1960	Naugatuck

AUTHORIZED (See Figure E-68)

Project	Map Number	Total Storage (Acre-feet)	Flood Control Storage (Acre-feet)	Estimated Total Cost ($1,000)	Year Authorized	River
Trumbull (UD)	30	13,850	6,080	10,300.0	1966	Pequonnack

INACTIVE (See Figure E-68)

Project	Map Number	Total Storage (Acre-feet)	Flood Control Storage (Acre-feet)	Estimated Total Cost ($1,000)	Year Authorized	River
Andover	10	16,800	16,800	10,682.5	1941	Hop
South Coventry	11	36,900	36,900	22,019.1	1941	Willimantic

UD – Under Design

PROJECTED FLOOD DAMAGE

AREA 10

Thames·Housatonic River Basins

Emphasized Objective: ALL

FIGURE E-41

AREA II   LAKE CHAMPLAIN AND
ST. LAWRENCE RIVER DRAINAGE
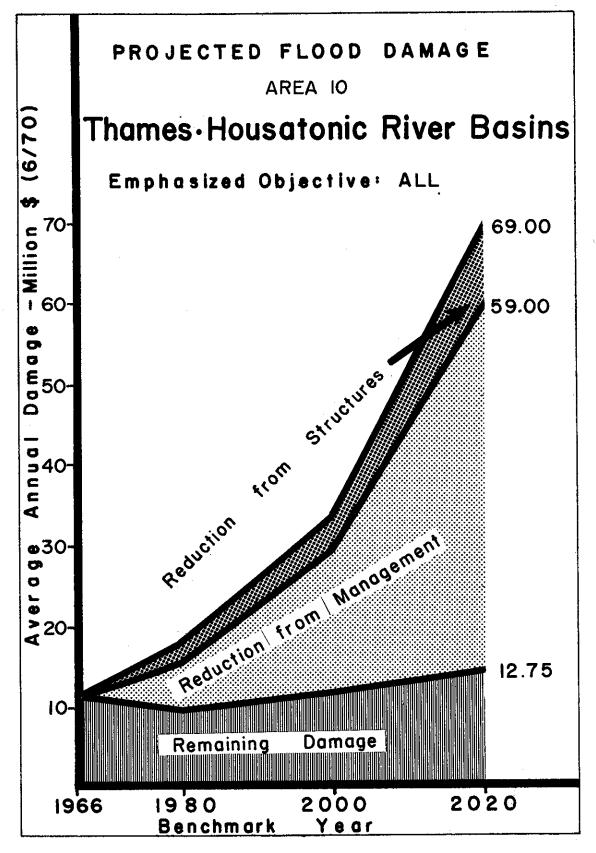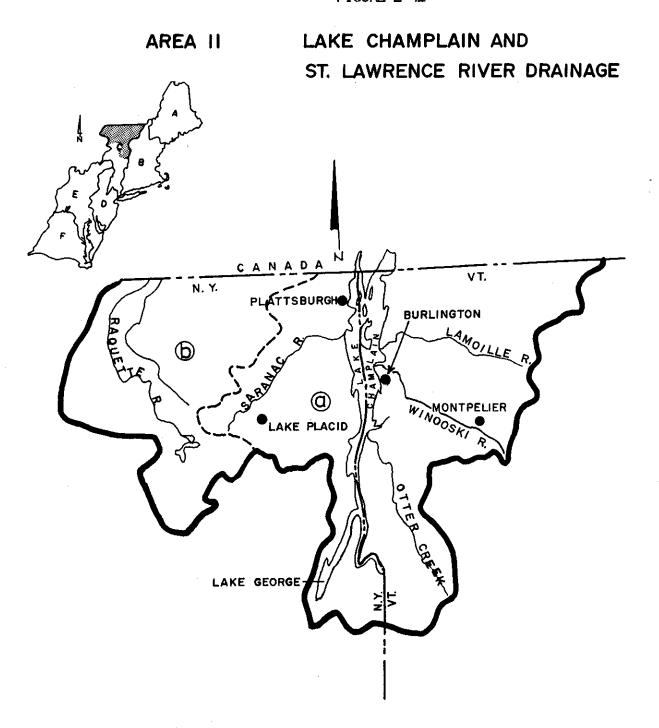
AREA 11. LAKE CHAMPLAIN AND ST. LAWRENCE RIVER DRAINAGE

Area 11, with a total drainage area of 11,900 square miles, is divided into: Sub-area 11a, consisting of all United States rivers and streams draining into, and including Lake Champlain; and Sub-area 11b, which includes all rivers and streams east of, and, including the Grass River, which drain into the St. Lawrence River. Sub-area 11a contains about 70% of the total drainage area.

The total usable storage in Sub-area 11a amounts to about 265,000 acre-feet. Most of the storage in this Sub-area is used for power, with some 60,000 acre-feet provided for flood control on the Winooski River. Sub-area 11b contains about 218,000 acre-feet of usable storage, used primarily for power and recreation. More than 90% of this storage is located along the Raquette River.

FLOOD DAMAGE REDUCTION

Area 11 flood damages include only those damages sustained from flooding on major tributaries within the St. Lawrence River and Lake Champlain drainage areas located in the United States. Main stem flood damages are significant only in Sub-area 11a, where, under January 1966 conditions, they are distributed as follows: Otter Creek – 53%; Winooski River – 20%, and Other Streams – 27%.

Overall flooding is a less serious problem in this Area. Existing and projected damages are the lowest of any Area in Sub-region C. Many of the streams in the Area are subject to some flow regulation by small power dams, reservoirs and natural lakes. Floods of record on these streams have been about 30 times the average stream-flows. The highest floods of record occurred on November 4, 1927, and March 19 and 20, 1966.

All projects constructed prior to January 1966 were considered effective in reducing future damages. No differences between objectives were apparent, and additional local protection projects and increased implementation of flood plain management measures are considered as effective means of reducing future damages. A flood plain management effectiveness factor of 40% was used. An additional need for local flood protection is foreseen at Rutland, Vt., in 1980 and a possibility for local protection exists at Waterbury, Vt.

The status of Federal flood damage reduction projects in Area 11 is shown in Table E-20.

WATER MANAGEMENT

Average annual runoff in Area 11 is approximately 12,145 m.g.d. The existing minimum monthly flow (shortage index 0.01) is 2,700 m.g.d.,

TABLE E-20
STATUS OF FLOOD DAMAGE REDUCTION PROJECTS - AREA 11

LOCAL PROTECTION PROJECTS
(Map Symbol ▲)

EXISTING (See Figure E-67)

Project	Map Number	Total Cost ($1,000)	Year Completed	River
Lamoille	38	50.0	1938	Lamoille
Richford	39	222.0	1963	Missisquoi
Middlesex-Montpelier	40	1/	1938	Winooski

AUTHORIZED (See Figure E-68)

Project	Map Number	Estimated Total Cost ($1,000)	Year Authorized	River
Rutland	36	5,810.0	1961	East-Otter Brooks
Waterbury	37	7,600.0	1941	Winooski

INACTIVE (See Figure E-68)

Project	Map Number	Estimated Total Cost ($1,000)	Year Authorized	River
Hardwick	15	153.2	1936	Lamoille
Proctor	16	119.0	1936	Otter Brook

FLOOD STORAGE PROJECTS
(Map Symbol □)

EXISTING (See Figure E-67)

Project	Map Number	Total Storage (Acre-feet)	Flood Control Storage (Acre-feet)	Total Cost ($1,000)	Year Completed	River
East Barre	36	12,050	12,050	1/	1935	Jail Brook
Waterbury	37	64,700	27,700	1/	1938	Waterbury
Wrightsville	38	20,300	20,300	1/	1935	North Branch Winooski

1/ These projects are part of the Winooski River Project which has a total cost of $13,864,300.

and the corresponding seven-day minimum is about 60% of this total, or
1,610 m.g.d. (See Appendix C). The addition of 30 m.g.d. as an allow-
ance for consumptive losses, results in an existing firm resource
available for use of about 1,640 m.g.d., or 13% of the average runoff.

The practical limit of development within the Area, based on
potential yield of new surface storage and additional ground water,
would provide a maximum available resource of 3,473 m.g.d., or 29% of
the average runoff. Potential sources which would develop the increase
of 1,833 m.g.d., include major storage, accounting for 49% of the
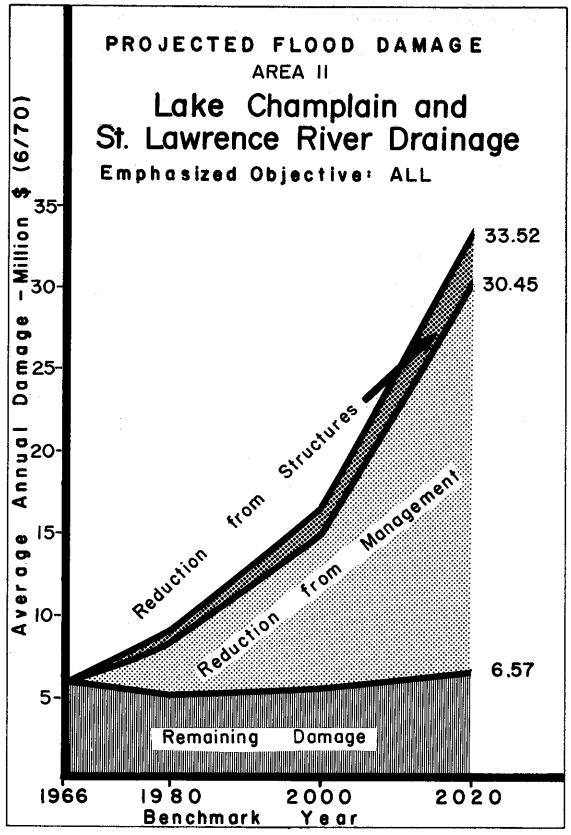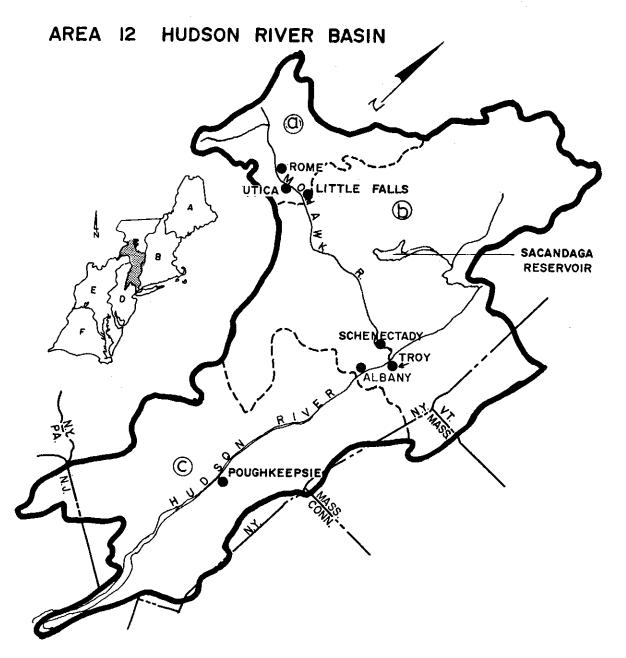increase; upstream storage, 19%, and ground water development, 32%.

PROJECTED FLOOD DAMAGE
AREA II
Lake Champlain and
St. Lawrence River Drainage
Emphasized Objective: ALL

FIGURE E-43

AREA 12 HUDSON RIVER BASIN

AREA 12.   HUDSON RIVER BASIN

The Hudson River Basin has a drainage area of 13,366 square
miles, with about 10% located in Sub-Area 12a, the Mohawk River above
Little Falls, N. Y.; about 55% in Sub-Area 12b, the area above Albany,
N.Y., excluding 12a; and about 35% in 12c, the remainder of the Basin.

Area 12's existing usable storage amounts to about 2 million
acre-feet, all in non-Federal reservoirs. Sub-area 12a contains about
7% of the total existing storage, operated primarily for navigation
with flood control storage provided as a secondary purpose. Storage in
Sub-area 12b is about 57% of the Area's total and is operated mainly
for flood control and low flow regulation. The remainder of the Area's
storage, located in Sub-area 12c, is used mainly for municipal supply
and recreation purposes, and includes storage for diversions from the
Delaware River Basin for the municipal supply of New York City.

FLOOD DAMAGE REDUCTION

Area 12 flood damages include only those occurring along the
main stems and major tributaries. Average annual damages, under
January 1966 conditions, are distributed as follows: Hudson River -
75%; and Mohawk River - 25%.

Current flood conditions reflect a 26% reduction in damages
from existing Federal projects. Most of this reduction occurs in
the Hoosic River Basin. Record floods along the main stems range from
15 to 20 times the average streamflow, while floods of up to 60 times
the average flows have occurred along the major tributaries. Area 12
flood damages are moderate and about average for Sub-region C.

No clear differences exist between objective in this Area.
A combination of structural and non-structural devices seem best suited
for reducing future damages. Flood plain management techniques are
considered to have an average chance of success in this Area, and an
effectiveness factor of 35% is considered attainable.

Local protection projects considered as effective in 1980 are
located at Yonkers, Rome, Schenectady, North Ellenville, South Ellen-
ville and Rosendale.

The status of Federal flood damage reduction projects in Area
12 is shown in Table E-21.

WATER MANAGEMENT

Average annual runoff in Area 12 is approximately 13,190 m.g.d.
The existing minimum monthly flow (shortage index 0.01) is 2,400 m.g.d.,
and the corresponding seven-day minimum is about 55% of this total, or
1,325 m.g.d. (See Appendix C). The addition of 96 m.g.d. as an allowance

TABLE E-21
STATUS OF FLOOD DAMAGE REDUCTION PROJECTS — AREA 12

LOCAL PROTECTION PROJECTS
(Map Symbol ▲)

EXISTING (See Figure E-67)

Project	Map Number	Total Cost ($1,000)	Year Completed	River
Adams	41	7,937.0	1960	Hoosic
Herkimer	42	1,494.7	1964	Mohawk
Hoosic Falls	43	1,144.6	1952	Hoosic
North Adams (emergency)		41.6	1951	Hoosic
North Adams	44	18,752.0	1962	Hoosic
Pleasant Valley	45	139.0	1958	Wappinger Creek
Roaring Branch-Bennington (emergency)		46.0	1951	Hoosic
Roaring Branch-East Arlington	46	10.0	1950	Batten Kill
South Amsterdam	47	1,542.0	1965	Mohawk
Wallkill River	48	1,337.4	1938	Wallkill

AUTHORIZED (See Figure E-68)

Project	Map Number	Estimated Total Cost ($1,000)	Year Authorized	River
North Ellenville	19	3,840.0	1962	Bear Kill
Roaring Branch-Bennington (UD)	20	484.0	1941	Roaring Branch, Walloomsac
Rome	21	610.0	1958	Mohawk
Rosendale(UC)	22	3,685.0	1962	Rondout Creek
South Ellenville	23	2,043.0	1962	North Gully
Yonkers	6	2,810.0	1965	Saw Mill

INACTIVE (See Figure E-68)

Project	Map Number	Estimated Total Cost ($1,000)	Year Authorized	River
Waterford	8	3,749.8	1938	Mohawk-Hudson

UNDER CONSIDERATION (See Figure E-68)

Project	Map Number	Estimated Total Cost ($1,000)		River
Schenectady	46	2,320.0		Mohawk

UD — Under Design
UC — Under Construction

for consumptive losses and 840 m.g.d. developed for export to Area 13, results in an existing firm resource available for use of about 2,261 m.g.d., or 17% of the average runoff.

The practical limit of development within the Area, based on potential yield of new surface storage and additional ground water, would provide a maximum available resource of 7,838 m.g.d., or 59% of the average runoff. Potential sources which would develop the increase of 5,577 m.g.d., include major storage, accounting for 61% of the increase; upstream storage, 28%, and ground water development, 11%.

PROJECTED FLOOD DAMAGE

AREA 12

Hudson River Basin

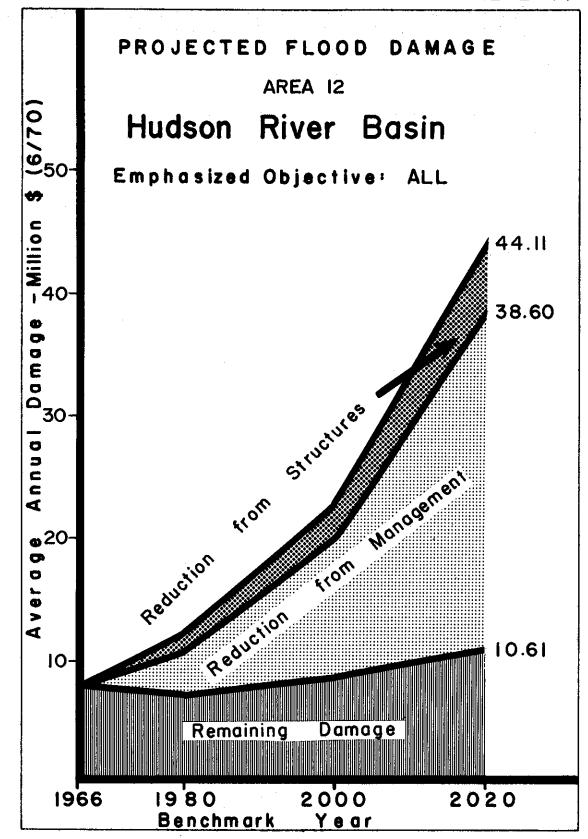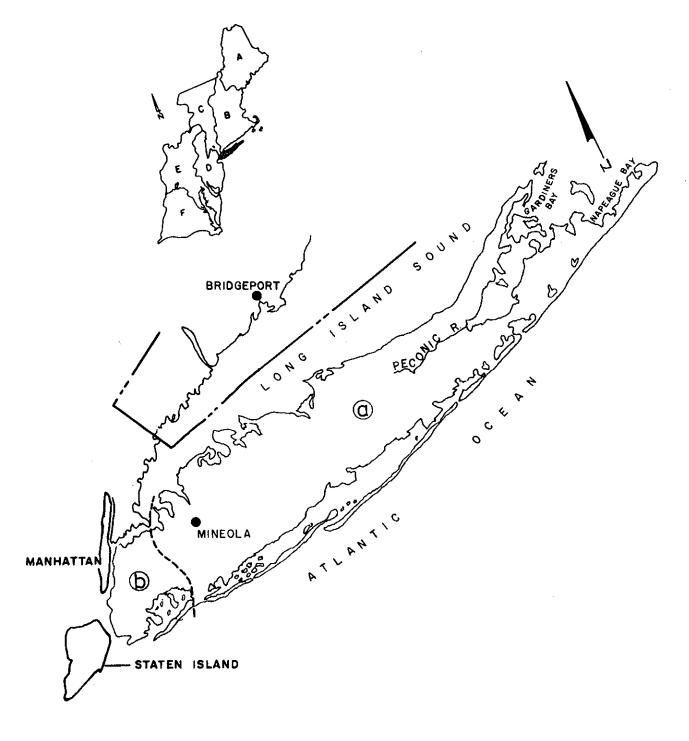Emphasized Objective: ALL

FIGURE E-45

AREA 13   SOUTHEASTERN NEW YORK METROPOLITAN AREA

AREA 13. SOUTHEASTERN NEW YORK METROPOLITAN AREA

The Southeastern New York Metropolitan Area has a total
drainage area of 1,901 square miles. Sub-area 13b, which includes the
Southeastern portion of Westchester County and the five New York City
Boroughs, contains about 27% of the drainage area; and Sub-area 13a,
Nassau and Suffolk Counties on Long Island, the remainder. The only
significant existing reservoir in the Area is on the Bronx River in
Sub-area 13b, and is used for the water supply of New York City.

FLOOD DAMAGE REDUCTION

Area 13 flood damages include those caused by hurricane and
tidal flooding, as well as flooding in the coastal streams on Long
Island and some coastal streams in Westchester County.

There are no existing structural flood damage reduction de-
vices in the Area, although the existing and projected flood damages
are the highest of any Area in Sub-region C. The potential exists for
catastrophic losses from hurricane and tidal flooding. It is estima-
ted that a recurrence of the 1821 hurricane, under January 1966 condi-
tions, coincident with high tide, would cause nearly $4.2 billion
(June 1970 prices) in damages.

No clear differences between objectives exist in this Area.
Flood plain management measures are unlikely to have a high degree of
effectiveness, because of heavy pressure to develop flood-prone areas
and the relatively sporadic nature of tidal and hurricane flooding.
A flood plain management effectiveness factor of 20% has been used.
A need also exists for structural means of flood damage reduction and
hurricane protection.

Projects assumed operational by 1980, include local protec-
tion projects at East Rockaway-Rockaway Inlet, Staten Island and Fire
Island-Montauk Point. Local protection projects assumed operational
by 2000, include Westchester County Streams, Coney Island and Jones
Inlet-East Rockaway.

The status of Federal flood damage reduction projects in Area
13 is shown in Table E-22.

TABLE E-22
STATUS OF FLOOD DAMAGE REDUCTION PROJECTS – AREA 13

LOCAL PROTECTION PROJECTS
(Map Symbol ▲)

AUTHORIZED (See Figure E-68)

Project	Map Number	Estimated Total Cost ($1,000)	Year Authorized	River
East Rockaway-Rockaway Inlet and Jamaica Bay	24	77,720.0	1965	Atlantic Ocean
Fire Island-Montauk Point	25	85,470.0	1960	Atlantic Ocean
Staten Island	26	19,180.0	1965	Atlantic Ocean

UNDER CONSIDERATION (See Figure E-68)

Project	Map Number	Estimated Total Cost ($1,000)	River
Coney Island	3	20,000.0	Atlantic Ocean
Jones Inlet-East Rockaway	4	32,200.0	Atlantic Ocean
Westchester Coastal Streams	5	3,000.0	Mamaroneck-Sheldrake

WATER MANAGEMENT

Average annual runoff in Area 13, including sub-surface outflow of ground water, is approximately 1,900 m.g.d. About 910 m.g.d. of this represents surface outflow, most of which is derived from ground water. The existing minimum monthly streamflow (shortage index 0.01) is 220 m.g.d., and the corresponding seven-day minimum is about 85% of this total, or 185 m.g.d. (See Appendix C).

Because of the unique hydrologic and geologic nature of Long Island, the developed ground water resource is not generally reflected in surface outflow measurements. Accordingly, the assumed existing available resource includes an allowance for this which is based on the estimated 1965 ground water use including consumption. This results in an existing firm resource available for use of 623 m.g.d. This does not include about 1,380 m.g.d., which can be imported into the Area for New York City.

The practical limit of development within the Area, based on potential yield of additional ground water, including 300 m.g.d. of anticipated artificial recharge, would provide a miximum available resource of 1,212 m.g.d., or 64% of the average runoff.
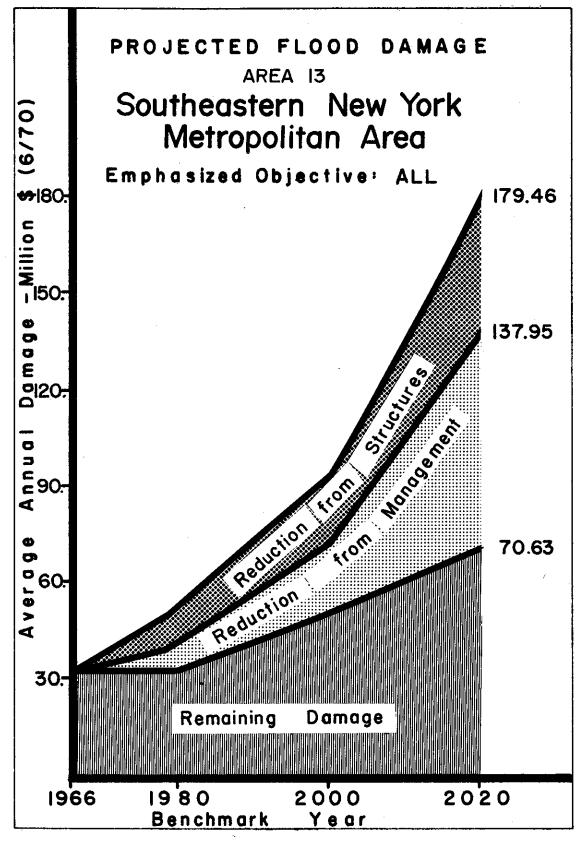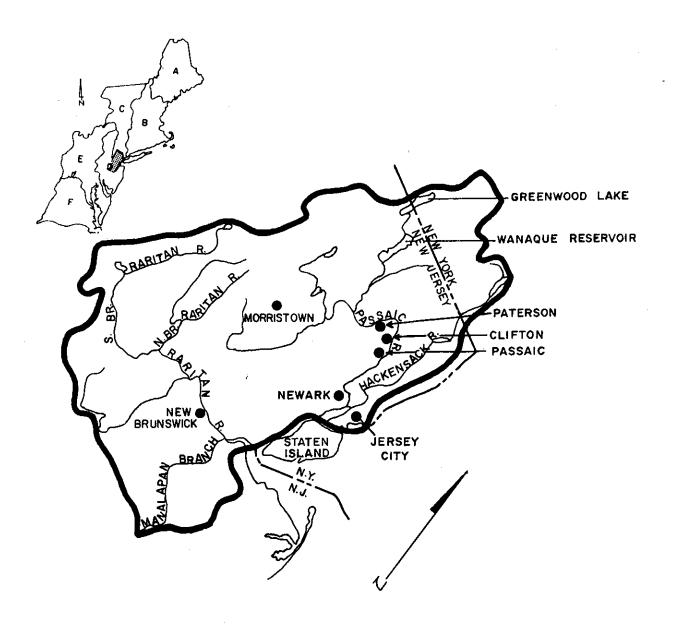
PROJECTED FLOOD DAMAGE
AREA 13
Southeastern New York Metropolitan Area
Emphasized Objective: ALL

FIGURE E-47

AREA 14 NORTHERN NEW JERSEY

AREA 14. NORTHERN NEW JERSEY

Northern New Jersey Streams, including the Passaic, Hacken-
sack, and Raritan Rivers, and smaller streams have a drainage area of
2,376 square miles. Total existing usable storage in the Area amounts
to about 401,000 acre-feet, with about 45% in the Passaic Basin, 9% in
the Hackensack Basin, and the remainder in the Raritan Basin. These
reservoirs are used almost exclusively for the municipal supply of the
Northern New Jersey Metropolitan Area.

FLOOD DAMAGE REDUCTION

Area 14 flood damages include only those damages occurring
along the main stems and major tributaries of the Passaic and Raritan
Rivers.

The Passaic River sustains the highest damages by far, and
its existing and projected damages are the highest of any river basin
in Sub-region D. Passaic flooding is an extremely serious problem,
primarily because of heavy flood plain development. Main stem record
floods have been about 20 times the average streamflow.

The October 1903 flood is the maximum of record for the
Passaic Basin. It caused estimated damages of some $24.7 million, and
would cause about $360 million (June 1970 prices) in damages if it were
to recur under 1966 conditions.

Prevalent public attitudes in Area 14 do not favor increased
storage, particularly single purpose flood damage reduction devices.
A great deal of existing flood plain development, and heavy pressure
for further development, contribute to a low rating for flood plain
management effectiveness. A 20% effectiveness factor was used for all
objectives, with State and local government support.

A substantial difference exists between objectives for this
Area. The major difference is the addition of the Passaic mainstream
project in 2000 under the National Income and Regional Development objec-
tives. A high interest in the environmental and ecological aspects of
water development preclude this project from being placed under the
Environmental Quality objective.

It has also been concluded that local protection projects are
needed and have been assumed operational as necessary for all objec-
tives. Projects assumed operational in 1980 include: Elizabeth,
Crab Island, Raritan Arsenal Levee, Westwood-Hillsdale, Rahway, South
Branch, South Orange-West Orange, Springfield-residential and
Springfield-industrial. Projects assumed operational in 2000 include:
Arthur Kill-Kill Van Kull, Hackensack Meadows, Oakland, Suffern, N.Y.-
Mahwah, N.J., Lodi, Haledon and Hillburn.

The status of Federal flood damage reduction projects in Area 14 is shown in Table E-23.

WATER MANAGEMENT

Average annual runoff in Area 14 is approximately 2,580 m.g.d. The existing minimum monthly flow (shortage index 0.01) is 855 m.g.d., and the corresponding seven-day minimum is about 85% of this total, or 735 m.g.d. (See Appendix C). The addition of 117 m.g.d. as an allowance for the portion of the consumptive losses reflected in streamflow records, results in an existing minimum resource available for use of about 852 m.g.d., or 33% of the average runoff. This does not include any import from Area 15, Under the Supreme Court decree of 1954, the State of New Jersey is authorized to divert up to 100 m.g.d. out of the Delaware. In 1965, the maximum monthly diversion was 71 m.g.d. and the annual average was 61 m.g.d.

The practical limit of development within the Area, based on potential yield of new surface storage and additional ground water, would provide a maximum available resource of 1,496 m.g.d., or 58% of the average runoff. Potential sources which would develop the increase of 644 m.g.d., include major storage, accounting for 46% of the increase; upstream storage, 39%, and ground water development, 15%.

TABLE E-23
STATUS OF FLOOD DAMAGE REDUCTION PROJECTS – AREA 14

LOCAL PROTECTION PROJECTS
(Map Symbol ▲)

EXISTING (See Figure E-67)

Project	Map Number	Total Cost ($1,000)	Year Completed	River
Rahway	49	1,221.8	1967	Rahway
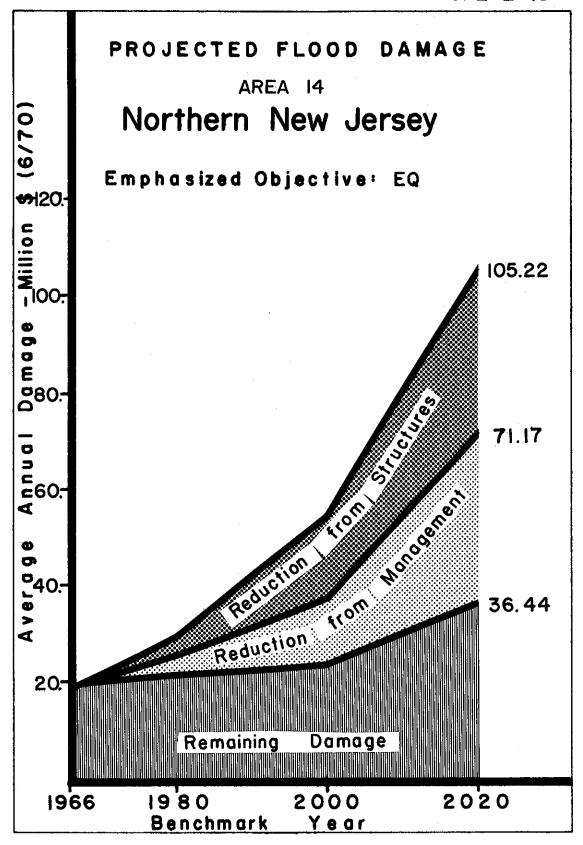
AUTHORIZED (See Figure E-68)
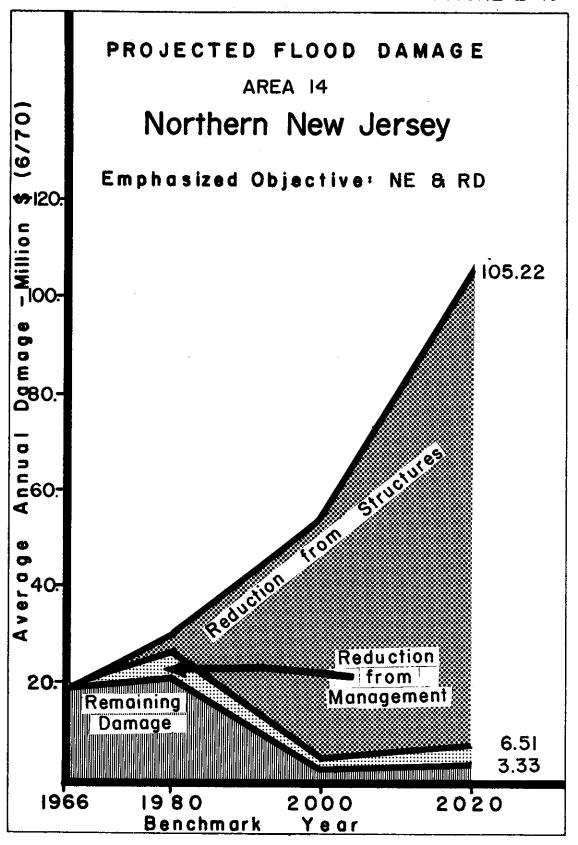
Project	Map Number	Estimated Total Cost ($1,000)	Year Authorized	River
Elizabeth	27	20,700.0	1965	Elizabeth
South Orange	28	4,000.0	1965	Rahway

UNDER CONSIDERATION (See Figure E-68)
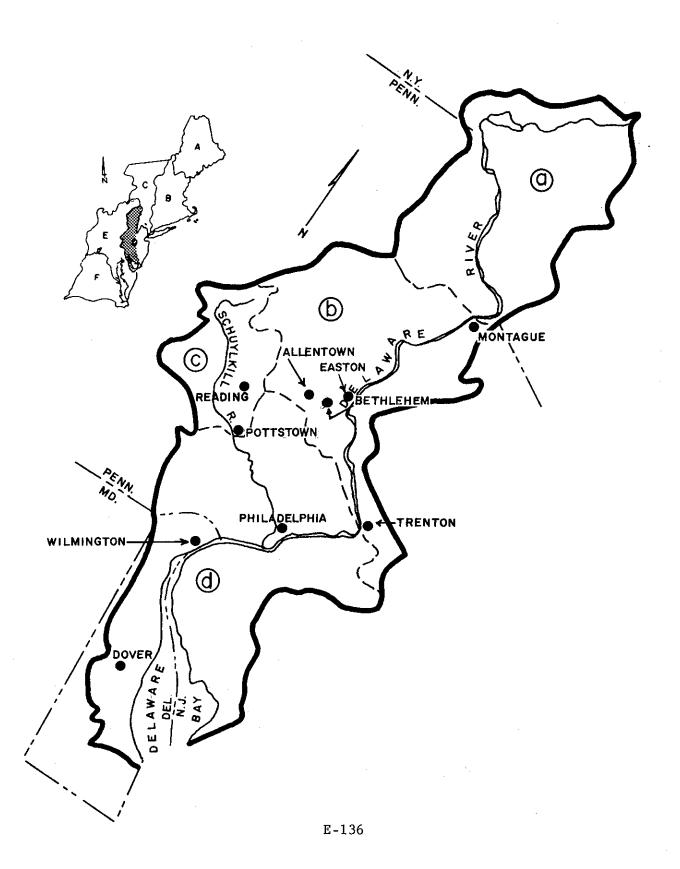
Project	Map Number	Estimated Total Cost ($1,000)	River
Arthur Kill-Kill Van Kull	13	12,290.0	Arthur Kill-Kill Van Kull
Hackensack Meadows	14	122,000.0	Hackensack
Westwood-Hillsdale	12	8,100.0	Pascack Brook
Hillburn	47	270.0	Ramapo
Haledon-Prospect Park	15	3,990.0	Molly Ann's Brook
Lodi	16	3,450.0	Saddle
Mainstream Passaic River and Associated Works 1/	19	586,950.0	Passaic
Oakland	17	7,710.0	Ramapo
Suffern-Mahwah	18	1,800.0	Mahwah
Orange-West Orange	6	1,539.0	Rahway
South Branch	7	1,011.0	Rahway
Springfield-Industrial	8	709.0	Rahway
Springfield-Residential	9	1,690.0	Rahway
Crab Island	10	69,025.0	Raritan
Raritan Arsenal Levee	11	9,573.0	Raritan

1/ Combined local protection and flood storage project.
   Includes 256,000 acre-feet of flood control storage.

PROJECTED FLOOD DAMAGE

AREA 14

Northern New Jersey

Emphasized Objective: EQ

PROJECTED FLOOD DAMAGE

AREA 14

Northern New Jersey

Emphasized Objective: NE & RD

FIGURE E-50

AREA 15   DELAWARE RIVER BASIN

AREA 15.   DELAWARE RIVER BASIN

        The Delaware River Basin, encompassing portions of New York,
New Jersey, Pennsylvania and Delaware, drains some 12,765 square miles.
Sub-area 15a, the area above Montague, N.J., contains about 27% of the
total; Sub-area 15b, the local area above Trenton, N.J., about 28%;
Sub-area 15c, the Schuylkill River Basin above Pottstown, Pa., about
9%; and Sub-area 15d, the remainder of the Delaware Basin, about 36%.
Total existing usable storage, including Beltzville Lake, totals about
1.4 million acre-feet, primarily for water supply and flood control.
Tocks Island Lake would provide about 750,000 acre-feet of additional
usable storage.

FLOOD DAMAGE REDUCTION

        Area 15 flood damages include some generated by hurricane,
coastal stream and tidal flooding, although they are caused primarily
by Delaware Basin flooding. Average annual damages, under January 1966
conditions, are distributed as follows: Main Stem - 43%; Small Tri-
butaries (Coastal Tidal) - 18%; Lackawaxen River - 3%; Lehigh River -
15%; Schuylkill River - 20%, and the Christina River - 1%.

        Existing projects, under 1966 conditions, reduced damages by
24%. The flood of record occurred on August 19 and 20, 1955, causing
flows in excess of 100 times the average streamflows on major tri-
butaries. Estimated damages of some $105 million were caused by this
flood, and if it were to recur under 1966 conditions, estimated damages
would reach $208 million, in June 1970 prices. Record flows on the
main stem have averaged about 30 times the average flow.

        No differences between objectives were apparent in Area 15.
The construction of single-purpose flood damage reduction storage
structures, in addition to already authorized projects, is not con-
sidered likely. However, there is a need for additional local protec-
tion projects. All projects constructed prior to 1966 were considered
as effective in reducing damages. The Beltzville Lake Project, under
construction, is also considered as effective in 1966.

        Storage projects considered effective in 1980 include Blue Marsh,
Trexler and Tocks Island; local protection projects at Darby and Cobbs
Creek, Martins Creek, Tamaqua, Delhi, Pottstown, Trouts Creek, East
Branch, Chester and Newton Creek, and the Delaware Coast Hurricane Pro-
tection Project. Projects considered effective in 2000 include the
Aquashicola and Maiden Creek Reservoirs, and the Liberty, Livingston
Manor, Pond Eddy, Walton and Wurtsboro Local Protection Projects.

        Flood plain management effectiveness is expected to be aver-
age in the Area, with an effectiveness factor of 35%.

The status of Federal flood damage reduction projects in Area 15 is shown in Table E-24.

WATER MANAGEMENT

Average annual runoff in Area 15 is approximately 13,200 m.g.d. The existing minimum monthly flow (shortage index 0.01) is 2,800 m.g.d., and the corresponding seven-day minimum is about 65% of this total, or 1,800 m.g.d. (See Appendix C). With the Tocks Island and Beltzville Lakes in operation, and a minimum flow at Montaque, N.J., of 1,130 m.g.d., the latter flow would be about 4,075 m.g.d. The addition of 160 m.g.d. for those consumptive losses not included, and 605 m.g.d. developed for export to Areas 12 and 14, results in a firm resource available for use of 4,840 m.g.d., or 37% of the average runoff. This does not include about 25 m.g.d. which can be imported from Area 17.

The practical limit of development within the Area, based on potential yield of new surface storage and additional ground water, would provide a maximun available resource of 7,562 m.g.d., or 57% of the average runoff. Potential sources which would develop the increase of 2,722 m.g.d., include major storage, accounting for 44% of the increase; upstream storage, 33%, and ground water development, 23%.

TABLE E-24
STATUS OF FLOOD DAMAGE REDUCTION PROJECTS – AREA 15

LOCAL PROTECTION PROJECTS
(Map Symbol ▲)

EXISTING (See Figure E-67)

Project	Map Number	Total Cost ($1,000)	Year Completed	River
Allentown	50	1,615.6	1960	Lehigh
Bethlehem	51	5,653.0	1964	Lehigh
Chester	53	183.3	1954	Chester
Mt. Holly	52	283.7	1944	Rancocas Creek

AUTHORIZED (See Figure E-68)

Project	Map Number	Estimated Total Cost ($1,000)	Year Authorized	River
East Branch	38	486.0	1968	East Branch Delaware
Newton Creek	39	270.0	1966	Newton Creek

UNDER CONSIDERATION (See Figure E-68)

Project	Map Number	Estimated Total Cost ($1,000)	River
Chester	20	130.0	Chester Creek
Darby and Cobbs Creek	21	1,678.0	Cobbs Creek
Delhi	22	981.0	West Branch Delaware
Liberty	27	412.0	Louis Street Brook
Little Mill Creek	23	2,300.0	Little Mill Creek
Livingston Maner	28	1,460.0	Little Beaver Kill
Martins Creek	24	1,000.0	Martins Creek
Pond Eddy	29	54.0	Mill Brook
Pottstown	25	3,400.0	Schuylkill
Tamaqua	26	2,355.0	Wabash Creek
Trout Creek	48	265.0	Trout Creek
Walton	30	1,030.0	West Branch Delaware
Wurtsboro	31	1,240.0	Wilsey Brook

TABLE E-24 (CONT.)
STATUS OF FLOOD DAMAGE REDUCTION PROJECTS – AREA 15

FLOOD STORAGE PROJECTS
(Map Symbol □)

EXISTING (See Figure E-67)

Project	Map Number	Total Storage (Acre-feet)	Flood Control Storage (Acre-feet)	Total Cost ($1,000)	Year Completed	River
Francis E. Walter	39	110,000	108,000	11,087.4	1961	Lehigh
General Edgar Jadwin	40	24,500	24,500	4,229.1	1960	Dyberry Creek
Prompton	41	23,700	20,300	4,225.6	1960	Lackawaxen

AUTHORIZED (See Figure E-68)

Project	Map Number	Total Storage (Acre-feet)	Flood Control Storage (Acre-feet)	Estimated Total Cost ($1,000)	Year Authorized	River
Belteville (U.C.)	16	68,250	27,000	22,200.0	1962	Pahopoco Creek
Blue Marsh	13	50,010	32,390	27,200.0	1962	Tulpehocken Creek
Tocks Island	17	845,000	323,500	259,000.0	1962	Delaware
Trexler	18	55,590	14,580	17,900.0	1962	Jordan Creek
Aquashicola	12	45,000	20,000	30,000.0	1962	Aquashicola Creek
Maiden Creek	15	114,000	38,000	42,000.0	1962	Maiden Creek

U.C. Under Construction

E-140

PROJECTED FLOOD DAMAGE

AREA 15

Delaware River Basin

Emphasized Objective: ALL
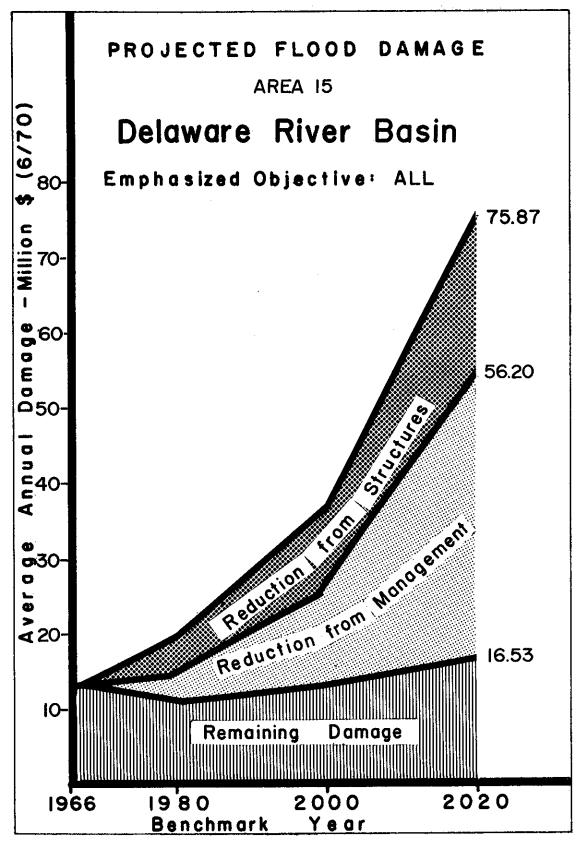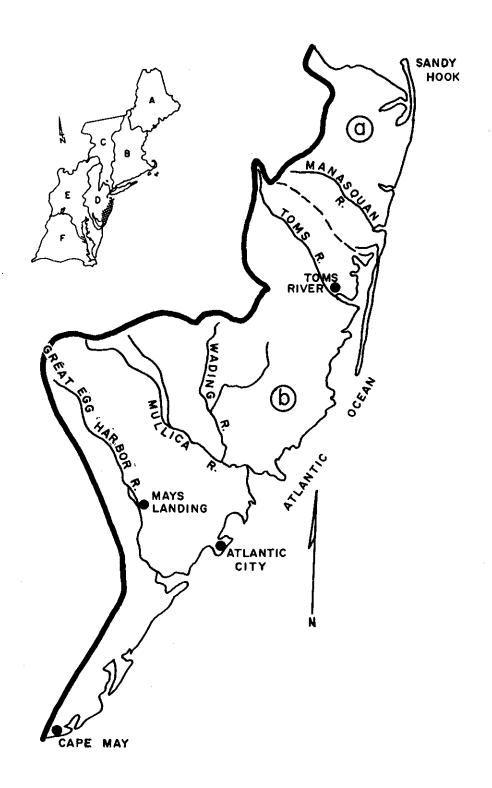
FIGURE E-52

AREA 16 COASTAL NEW JERSEY

AREA 16.   COASTAL NEW JERSEY

Area 16, consisting of Coastal New Jersey Steams draining into the lower bay of New York Harbor, and into the Atlantic Ocean between Sandy Hook and Cape May, N.J., has a total drainage area of 2,393 square miles. Sub-area 16b, which drains all rivers south of Monmouth County, contains about 85% of the drainage area; and Sub-area 16a, or most of Monmouth County, the remainder. The existing usable storage in the Area is very small and has no significant effect on streamflow.

FLOOD DAMAGE REDUCTION

Flood damges in Area 16 include only those caused by hurricane, coastal stream and tidal flooding. Average annual damages, under January 1966 conditions, are distributed as follows: Sandy Hook to Manasquan Inlet - 36%; Raritan and Sandy Hook Bays - 24%, and Manasquan Inlet South - 40%.

Coastal stream flooding is distinctly different in Sub-area 16a and Sub-area 16b. Record flows in Sub-area 16a have been about 75 times the average streamflows, and in Sub-area 16b, about 10 times average streamflows. Area 16's flood of record occurred with the storm of March 6-8, 1962, which caused estimated damages of some $123 million. If this flood were to recur under 1966 conditions, damages would total an estimated $200 million in June 1970 prices.

No apparent differences between objectives were noted in the Area. There is a need for the reduction of projected flood damages through the use of both structural and non-structural devices. All existing projects have been considered as effective in reducing projected flood damages. Structural measures for hurricane protection and tidal flood damage reduction have all been assumed operational by 1980.

Flood plain management measures will also be necessary to reduce projected damages, especially in Sub-area 16a, because of heavy pressure for further development and the flash flooding nature of the streams. Flood plain management measures are given a slightly less than average chance of success in this Area, and an effectiveness factor of 30% has been used.

The status of Federal flood damage reduction projects in Area 16 is shown in Table E-25.

TABLE E-25
STATUS OF FLOOD DAMAGE REDUCTION PROJECTS - AREA 16

LOCAL PROTECTION PROJECTS
(Map Symbol ▲)

AUTHORIZED (See Figure E-68)

Project	Map Number	Estimated Total Cost ($1,000)	Year Authorized	River
New Jersey Shore-Group I	40	29,574.0	1970	Atlantic Ocean

INACTIVE (See Figure E-68)

Project	Map Number	Estimated Total Cost ($1,000)	Year Authorized	River
Union Beach-Raritan	17	3,978.0	1962	Raritan to Shrewsbury

UNDER CONSIDERATION (See Figure E-68)

Project	Map Number	Estimated Total Cost ($1,000)	River
New Jersey Shore-Group II	32	24,150.0	Atlantic Ocean
New Jersey Shore-Group III	33	46,107.0	Atlantic Ocean
New Jersey Shore-Group IV	34	58,960.0	Atlantic Ocean

WATER MANAGEMENT

Average annual runoff in Area 16 is approximately 2,450 m.g.d. The existing minimum monthly flow (shortage index 0.01) is 968 m.g.d., and the corresponding seven-day minimum is about 80% of this total, or 781 m.g.d. (See Appendix C). The addition of 64 m.g.d. as an allowance for consumptive losses, results in an existing firm resource available for use of about 845 m.g.d., or 34% of the average runoff.

The practical limit of development within the Area, based on potential yield of new surface storage and additional ground water, would provide a maximum available resource of 1,065 m.g.d., or 43% of the average runoff. Potential sources which would develop the increase of 220 m.g.d., include major storage, accounting for 38% of the increase; upstream storage, 52%, and ground water development, 10%.
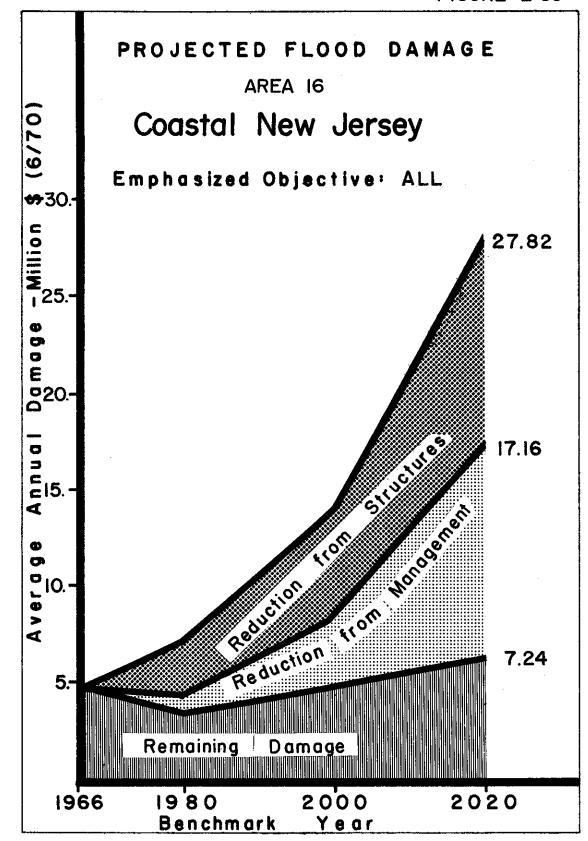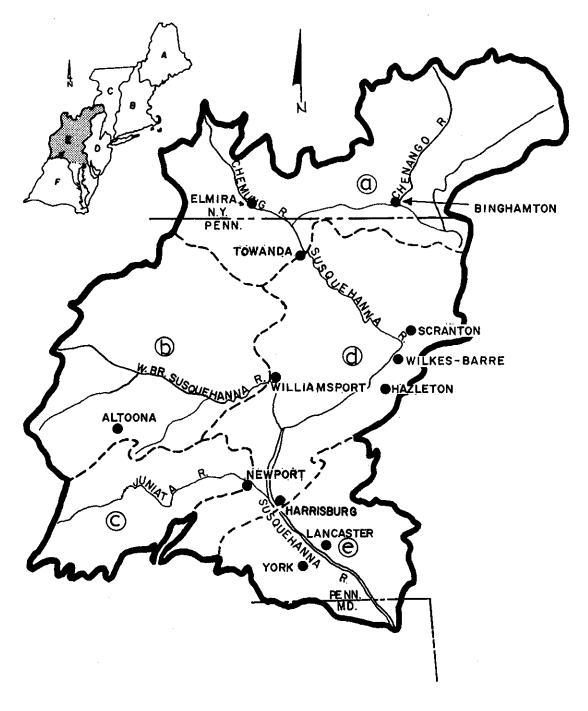
PROJECTED FLOOD DAMAGE

AREA 16

Coastal New Jersey

Emphasized Objective: ALL

FIGURE E-54

AREA 17 SUSQUEHANNA RIVER BASIN

AREA 17. SUSQUEHANNA RIVER BASIN

The Susquehanna River Basin, in parts of New York, Pennsylvania and a small portion in Maryland, has a drainage area of 27,510 square miles. Sub-area 17a, above Towanda, Pa. contains about 28% of the total drainage area; Sub-area 17b, above Williamsport, Pa., has about 21%; Sub-area 17c the Juniata River above Newport, Pa., about 12%; Sub-area 17d the local area above Harrisburg, Pa., about 26.5%; and Sub-area 17e, the remainder of the Susquehanna Basin, about 12.5%.

Total usable storage in the basin is about 735,000 acre-feet, for flood control, water supply, recreation and power. Completion of Lake Raystown will add about 724,000 acre-feet of usable storage.

FLOOD DAMAGE REDUCTION

Area 17 flood damages include those caused by main stem and major tributary flooding. Average annual damages and distributed, under January 1966 conditions as follows: Sub-area 17a - 34%; Sub-area 17b - 13%; Sub-area 17c - 14%; Sub-area 17d - 33%, and Sub-area 17e - 6%.

Existing projects in 1966, including a number of non-Federal storage and local protection projects, reduced damages by 49%. The damage reduction attributed to projects completed since 1966, or presently under design or construction, is 30%. The Type II Susquehanna River Basin Study was completed and forwarded for review to the Water Resources Council in February 1970.

Flooding of record occurred in March 1936, when two floods occurred within two weeks. This flooding resulted in estimated damages of $92 million, and if it were to recur under 1966 conditions, would cause an estimated $340 million (June 1970 prices) in damages. Record floods on the main stem have been about 20 times the average streamflows, with record floods on the major tributaries ranging higher and more directly effected by regulation.

Existing and projected damages on the Susquehanna are among the highest in the North Atlantic Region, despite the high degree of existing control. This is partly because of the large size of the basin, but mainly because of the topography as it influences development and flood patterns.

Differences were apparent between objectives, and a need was demonstrated for relatively more structural devices for increased industrial and economic gain under the Regional Development objective. Flood plain management is considered to have a better than average chance of success, due to public attitudes and topography. An effectiveness factor of 45% has been used for all objectives.

It should be noted, however, that this evaluation does not take into account the recent activation of the Susquehanna River Basin Commission. With the advent of this Commission a mechanism now exists for coordinating and implementing Basin-wide flood plain planning and management.

All projects constructed since 1966, and those presently under design or construction, have been considered as effective in the base year. Projects considered effective in 1980 for all objectives, include multi-purpose projects at Charlotte Creek Complex, South Plymouth, Fabius and Mud Creek, and local protection projects at Marathon, Westfield, Wyoming Valley and South Harrisburg. The following projects have been assumed as operational in 1980 solely for Regional Development: a multi-purpose project at Fivemile Creek, and local protection projects at Bloomsburg and Lock Haven. One project, the proposed East Guilford Reservoir, has been assumed effective by 2000 for all objectives.

The status of Federal flood damage reduction projects in Area 17 is shown in Table E-26.

WATER MANAGEMENT

Average annual runoff in Area 17 is approximately 24,890 m.g.d. The existing minimum monthly flow (shortage index 0.01) is 2,470 m.g.d., and the corresponding seven-day minimum is about 52% of this total, or 1,280 m.g.d. (See Appendix C). Allowance for yield from Lake Raystown raises the latter value to about 1,530 m.g.d. The addition of 211 m.g.d. for consumptive losses and export to Area 15, results in a firm resource available for use of 1,741 m.g.d., or 7% of the average runoff.

The practical limit of development within the Area, based on potential yield of new surface storage and additional ground water, would provide a maximum available resource of 8,756 m.g.d., or 35% of the average runoff. Potential sources which would develop the increase of 7,015 m.g.d., include major storage, accounting for 52% of the increase, upstream storage, 27%, and ground water development, 21%.

TABLE E-26
STATUS OF FLOOD DAMAGE REDUCTION PROJECTS — AREA 17

LOCAL PROTECTION PROJECTS
(Map Symbol ▲)

EXISTING (See Figure E-67)

Project	Map Number	Total Cost ($1,000)	Year Completed	River
Addison	54	952.1	1947	Canisteo
Avoca	55	505.7	1939	Cohocton
Bainbridge	56	578.5	1959	Newton Creek
Bath	57	682.0	1948	Cohocton
Binghampton	58	3,663.0	1943	Susquehanna
Canisteo	59	1,218.1	1948	Canisteo
Cincinnatus	60	16.3	1956	Otselic
Conklin and Kirkwood	61	86.0	1955	Susquehanna
Corning	62	2,469.9	1942	Cohocton
Cortland	63	375.8	1963	Tioughnioga
Elkland	64	1,898.0	1967	Cowanesque
Elmira	65	7,660.3	1950	Chemung
Endicott, Johnson City and Vestal	66	7,563.5	1960	Susquehanna
Greene	95	62.3	1951	Birdsall Creek
Hornell	67	4,558.7	1941	Canisteo
Kingston-Edwardsville	68	4,850.4	1943	Susquehanna
Lisle	69	729.2	1948	Tioughnioga
Monkey Run (Corning)	70	1,823.3	1955	Cohocton
Norwich	71	105.8	1950	Chenango
Owego	72	49.1	1952	Susquehanna
Oxford	73	142.0	1938	Chenango
Painted Post	74	465.0	1938	Cohocton
Plymouth	75	2,028.5	1948	Susquehanna
Scranton	76	6,090.0	1968	Lackawanna
Sherburne	77	51.2	1955	Chenango
Sunbury	78	6,295.8	1948	Susquehanna
Swoyersville-Forty Fort	79	3,006.4	1957	Susquehanna
Unadilla	80	1,368.5	1968	Martin Brook
Whitney Point Village	81	486.6	1948	Tioughnioga
Wilkes-Barre-Hanover Township	82	4,069.5	1943	Susquehanna
Williamsport	83	14,978.4	1955	Susquehanna

AUTHORIZED (See Figure E-68)

Project	Map Number	Estimated Total Cost ($1,000)	Year Authorized	River
Nichols (UD)	30	1,820.0	1955	Susquehanna-Wappasening Creek
Tyrone (UD)	31	15,480.0	1944	Little Juniata

UNDER CONSIDERATION (See Figure E-68)

Project	Map Number	Estimated Total Cost ($1,000)	River
Lock Haven	36	12,400.0	Susquehanna-Bald Eagle Creek
Marathon	37	1,810.0	Tioughnioga
South Harrisburg	38	5,180.0	Susquehanna-Paxton Creek
Westfield	39	990.0	Cowanesque
Bloomsburg	35	8,660.0	Susquehanna-Fishing Creek
Wyoming Valley	40	1,375.0	Susquehanna

UD - Under Design

FLOOD STORAGE PROJECTS
(Map Symbol ◻)

EXISTING (See Figure E-67)

Project	Map Number	Total Storage (Acre-feet)	Flood Control Storage (Acre-feet)	Total Cost ($1,000)	Year Completed	River
Almond	43	14,800	13,700	5,610.2	1949	Canacadea Creek
Alvin R. Bush	44	75,000	73,410	7,103.0	1966	Kettle Creek
Arkport	45	7,950	7,950	1,910.0	1939	Canisteo
Aylesworth Creek	46	1,700	1,700	1,974.0	1969	Aylesworth Creek
Curwensville	47	124,200	114,660	20,464.0	1965	West Branch Susquehanna
East Sidney	48	33,494	30,200	5,995.0	1950	Ouleout Creek
Foster Joseph Sayers	49	99,000	70,200	29,600.0	1970	Bald Eagle Creek
Indian Rock	50	28,000	28,000	5,061.2	1947	Codorus Creek
Stillwater	51	11,800	11,600	5,725.7	1965	Lackawanna
Whitney Point	52	86,440	74,000	5,321.0	1942	Otselic

AUTHORIZED (See Figure E-68)

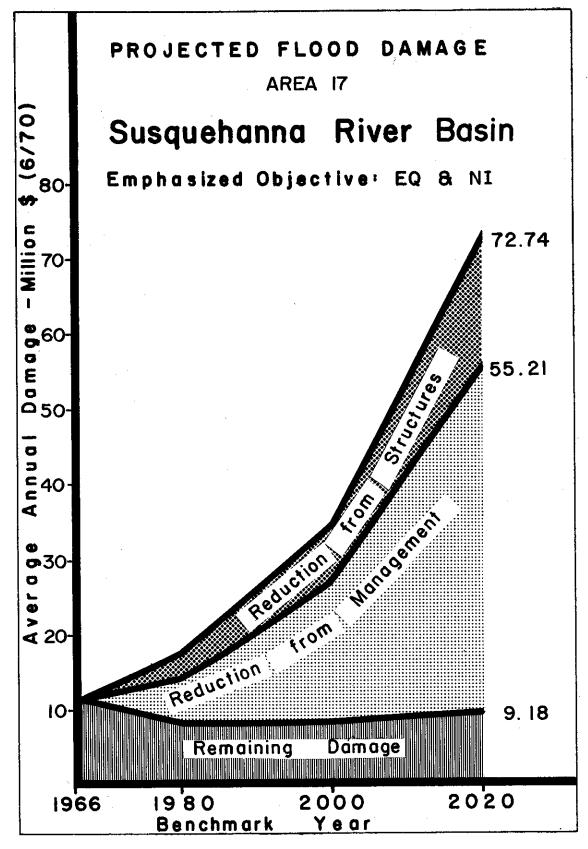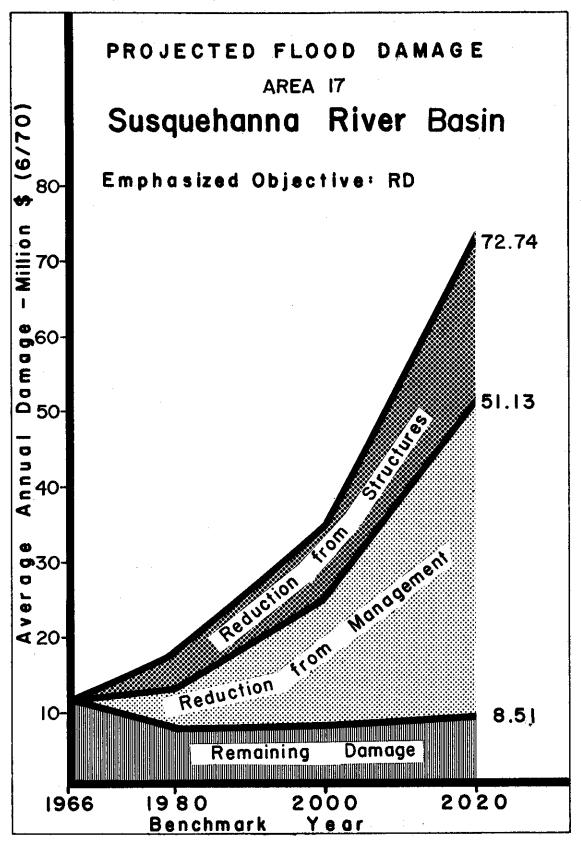| Project	Map Number	Total Storage (Acre-feet)	Flood Control Storage (Acre-feet)	Estimated Total Cost ($1,000)	Year Authorized	River
Cowanesque (UD)	20	171,000	82,000	46,600.0	1958	Cowanesque
Raystown (UC)	22	762,000	248,000	59,800.0	1962	Raystown Branch
Tioga-Hammond (UD)	24	125,000	120,000	28,200.0	1958	Tioga-Crooked Creek
Charlotte Creek Complex-Davenport Center	19	160,000	44,000	46,449.0	1936	Charlotte Creek
Genegantslet	21	30,200	20,200	16,900.0	1944	Genegantslet Creek
South Plymouth	23	55,500	17,000	28,700.0	1944	Canasawacta Creek
Copes Corner (D)	25	37,900		31,500.0	1936	Butternut Creek
Fall Brook (D)	26	1,400	1,400	1,965.0	1962	Fall Brook
West Oneonta (D)	27	34,500	34,500	20,000.0	1936	Otsego Creek

UNDER CONSIDERATION (See Figure E-68)

Project	Map Number	Total Storage (Acre-feet)	Flood Control Storage (Acre-feet)	Estimated Total Cost ($1,000)	River
Fabius	5	58,000	10,000	18,800.0	West Branch Tioughniaga
Fivemile Creek	6	60,000	18,000	33,800.0	Fivemile Creek
Mud Creek	7	58,000	10,000	24,500.0	Mud Creek
East Guilford	8	175,000	70,000	78,200.0	Unadilla

UC - Under Construction
UD - Under Design
D - Deferred

PROJECTED FLOOD DAMAGE
AREA 17
Susquehanna River Basin
Emphasized Objective: EQ & NI

PROJECTED FLOOD DAMAGE
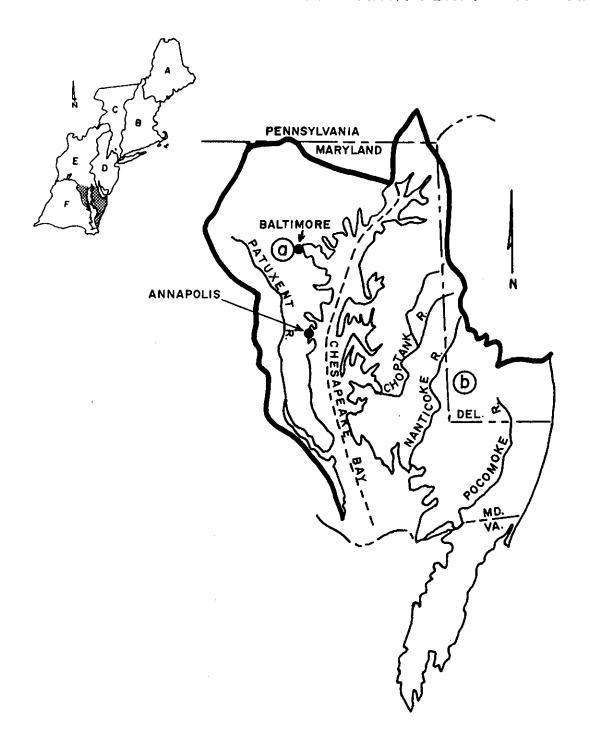AREA 17
Susquehanna River Basin

Emphasized Objective: RD

AREA 18

CHESAPEAKE BAY AND
DELMARVA PENINSULA DRAINAGE

AREA 18. CHESAPEAKE BAY AND DELMARVA PENINSULA DRAINAGE

Area 18 is divided into Sub-area 18a, the streams draining into the western shore of Chesapeake Bay between the Susquehanna and Potomac River Basins, and Sub-area 18b, all streams on the Delmarva Peninsula. The Area has a total drainage area of about 8,145 square miles. Sub-area 18b contains about 67% of the drainage area.

Existing major storage in the Area, is entirely on the western shore, and amounts to about 300,000 acre-feet, primarily for water supply.

FLOOD DAMAGE REDUCTION

Area 18 flood damages consist of bay and coastal stream, fluvial and tidal flooding. Average annual damages under January 1966 conditions are distributed as follows: Baltimore and Chesapeake Bay Fluvial - 6%; Baltimore and Chesapeake Bay Tidal - 50%; Nanticoke River - 5%; Patuxent River - 2%, and Atlantic Coastal - 37%.

The existing local flood protection project at Upper Marlboro reduced Area damages under 1966 conditions, by only 1%. However, little need is foreseen for additional fluvial flood damage reduction structures, because fluvial damages are only a small part of the total. A need does exist for some structural measures on the Atlantic Coast. Because of the sporadic nature of hurricane-induced tidal flooding, the potential effectiveness of flood plain management measures is not considered very high, and a 25% effectiveness factor was used for all objectives.

Differences in flood damage reduction programs for the three planning objectives were not apparent for this area. The Ocean City-Assateaque, Md., beach erosion and hurricane protection project was assumed operational in 1980 for all objectives.

The status of Federal flood damage reduction projects in Area 18 is shown in Table E-27.

TABLE E-27
STATUS OF FLOOD DAMAGE REDUCTION PROJECTS - AREA 18

LOCAL PROTECTION PROJECTS
(Map Symbol ▲)

EXISTING (See Figure E-67)

Project	Map Number	Total Cost ($1,000)	Year Completed	River
Upper Marlboro	84	741.0	1964	West Branch Patuxent
Delaware Coast	29	10,800.0	1970	Atlantic Ocean

UNDER CONSIDERATION (See Figure E-68)

Project	Map Number	Estimated Total Cost ($1,000)	River
Ocean City - Assateague, Md.	41	34,304.0	Atlantic Ocean

WATER MANAGEMENT

Average annual runoff in Area 18 is approximately 5,500 m.g.d. The existing minimum monthly flow (shortage index 0.01) is 1,225 m.g.d., and the corresponding seven-day minimum is about 76% of this total, or 935 m.g.d. (See Appendix C). The addition of 110 m.g.d. as an allowance for those consumptive losses not included and 40 m.g.d. developed for export to Area 19, results in an existing firm resource available for use of about 1,085 m.g.d., or 20% of the average runoff. This does not include allowance for import from Area 17.

The practical limit of development within the Area, based on potential yield of new surface storage and additional ground water, would provide a maximum available resource of 1,468 m.g.d., or 27% of the average runoff. Potential sources which would develop the increase of 383 m.g.d., include upstream storage, accounting for 58% of the increase, and ground water development, 42%.
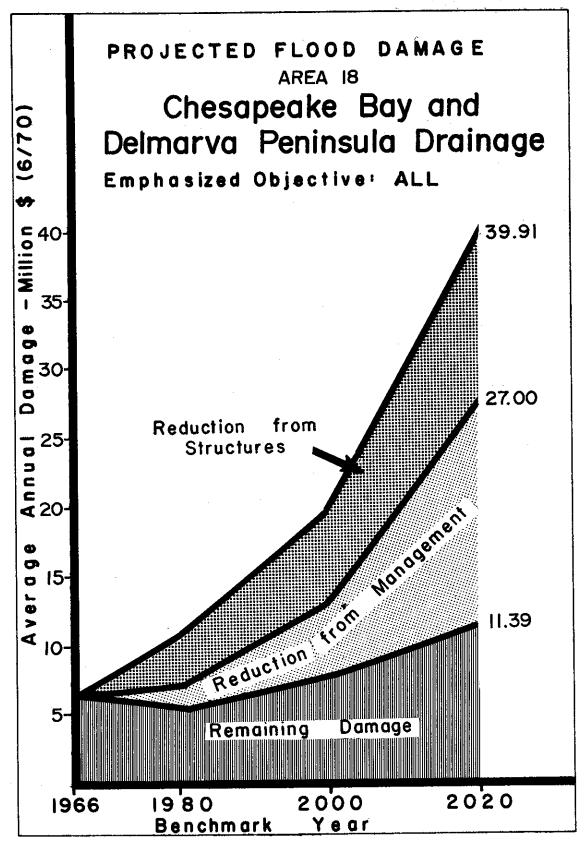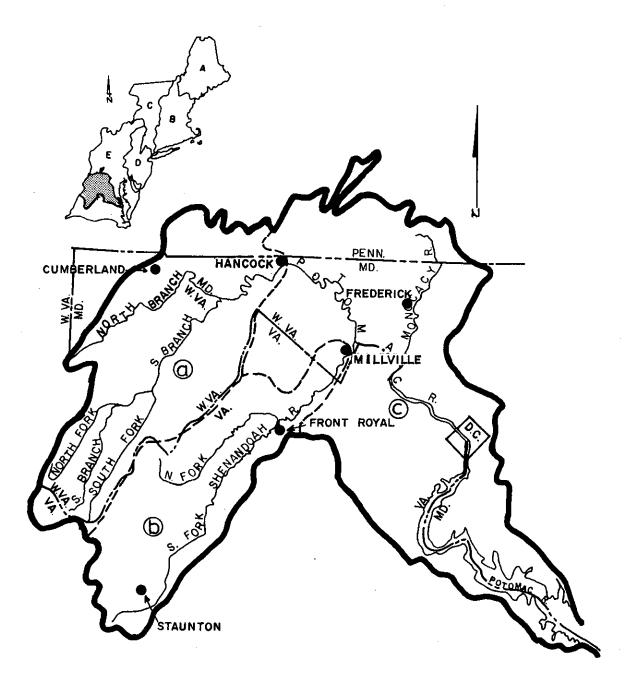
PROJECTED FLOOD DAMAGE
AREA 18
Chesapeake Bay and
Delmarva Peninsula Drainage
Emphasized Objective: ALL

FIGURE E-59

AREA 19 POTOMAC RIVER BASIN

AREA 19.   POTOMAC RIVER BASIN

The Potomac River Basin, draining the Nation's Capital and parts of Pennsylvania, Maryland, West Virginia and Virginia, has a total drainage area of 14,670 square miles. Sub-area 19a, above Hancock, Va., contains about 28% of the total drainage area; Sub-area 19b, the Shenandoah River above Millville, Va., contains about 21%; and 19c, the remainder of the Basin, about 51%. Existing usable storage in the Basin amounts to about 55,000 acre-feet, operated for flood control, recreation, water supply, power and low flow augmentation.

FLOOD DAMAGE REDUCTION

Area 19 flood damages include only those occurring along the main stem and major tributaries. Average annual damages are distributed, under January 1966 conditions, as follows: North Branch - 26%; South Branch - 12%; Shenandoah River - 4%; Main Stem - 55%, and remaining small tributaries - 3%.

Existing projects in 1966 reduced damages by 18%. Under a comprehensive river basin study completed in 1965, the Potomac Basin's flood damage reduction needs were recognized, and a number of multi-purpose structures were recommended to help alleviate damages. However, because of significant scenic and historic values in the Basin, some of those projects are now considered undesirable.

The major flood of record occurred on March 18 and 19, 1936, and caused estimated damages of $12.6 million. An estimated $33.8 million (June 1970 prices) in damages would be sustained if this flood were to recur under 1966 conditions. Record floods on the main stem have been about 50 times the average stream flow, with major tributary flooding often doubling that ratio.

Differences between objectives were evident in the Potomac Basin; although a need exists for combination of structural and nonstructural devices for all objectives in meeting flood damage reduction needs. Under the Environmental Quality objective, less need for structural devices is seen.

Flood plain management is considered to have an average chance of success, and an effectiveness factor of 40% was used for all objectives.

Structural measures considered effective in 1980 for all objectives, include the Bloomington multi-purpose project, and local protection projects at Fourmile Run and Anacostia. The North Mountain multi-purpose project is considered effective for all objectives in 2000, and the following projects are considered effective for all objectives in 2020: Licking Creek, Brocks Gap, Winchester, West Branch, Back Creek and Mount Storm multi-purpose projects. Under the

Regional Development and National Efficiency objectives, the Royal Glen multi-purpose project is considered effective in 2000 and the Seneca multi-purpose project in 2020. Under Environmental Quality, the Petersburg local protection project is considered effective in 2000.

The status of Federal flood damage reduction projects in Area 19 is shown in Table E-28

WATER MANAGEMENT

Average annual runoff in Area 19 is approximately 8,970 m.g.d. The existing minimum monthly flow (shortage index 0.01) is 1,110 m.g.d., and the corresponding seven-day minimum is about 60% of this total, or 670 m.g.d. (See Appendix C). The addition of 106 m.g.d. as an allowance for consumptive losses, results in an existing firm resource available for use of 776 m.g.d., or 9% of the average runoff. This does not include an import of about 40 m.g.d. from Area 18.

The practical limit of development within the Area, based on potential yield of new surface storage and additional ground water, would provide a maximum available resource of 3,552 m.g.d., or 40% of the average runoff. Potential sources which would develop the increase of 2,776 m.g.d., include major storage, accounting for 50% of the increase; upstream storage, 17%, and ground water development, 33%.

TABLE E-28
STATUS OF FLOOD DAMAGE REDUCTION PROJECTS – AREA 19

LOCAL PROTECTION PROJECTS
(Map Symbol ▲)

EXISTING (See Figure E-67)

Project	Map Number	Total Cost ($1,000)	Year Completed	River
Anacostia River	85	12,317.0	1959	Anacostia
Bayard	86	346.9	1964	Buffalo Creek
Bridgewater	87	136.5	1953	Potomac
Forest Heights	88	517.7	1964	Oxen Run
Kitzmiller	89	508.1	1964	North Branch Potomac
Ridgely, W. Va.-Cumberland,Md.	90	18,731.5	1959	Potomac-Willis Creek
Washington	91	493.9	1940	Anacostia-Potomac

AUTHORIZED (See Figure E-68)

Project	Map Number	Estimated Total Cost ($1,000)	Year Authorized	River
Anacostia	32	10,980.0	1970	Anacostia
Fourmile Run	33	735.0	1970	Fourmile Run

UNDER CONSIDERATION (See Figure E-68

Project	Map Number	Estimated Total Cost ($1,000)	River
Petersburg	42	3,337.0	South Branch Potomac

STATUS OF FLOOD DAMAGE REDUCTION PROJECTS -- AREA 19
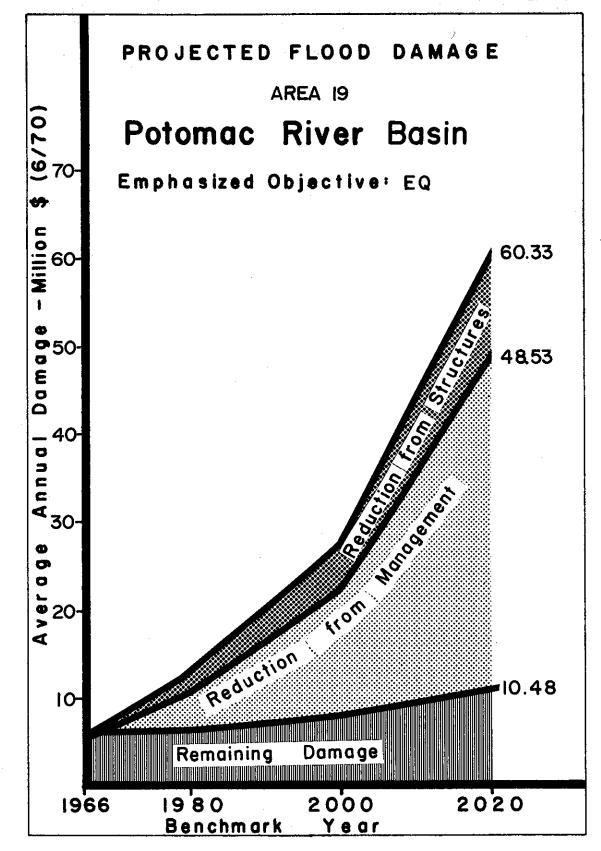
FLOOD STORAGE PROJECTS
(Map Symbol □)

EXISTING (See Figure E-67)

Project	Map Number	Total Storage (Acre-feet)	Flood Control Storage (Acre-feet)	Total Cost ($1,000)	Year Completed	River
Savage River	53	20,000	16,000	6,237.0	1952	Savage

AUTHORIZED (See Figure E-68)

Project	Map Number	Total Storage (Acre-feet)	Flood Control Storage (Acre-feet)	Estimated Total Cost ($1,000)	Year Authorized	River
Bloomington	28	130,900	36,200	90,400.0	1962	Potomac

UNDER CONSIDERATION (See Figure E-68)

Project	Map Number	Total Storage (Acre-feet)	Flood Control Storage (Acre-feet)	Estimated Total Cost ($1,000)	River
North Mountain	9	195,000	1/	26,046.6	Back Creek
Royal Glen	10	338,000	90,000	25,670.0	South Branch Potomac
Back Creek	11	46,900	1/	11,809.5	Back Creek
Brocks Gap	12	187,000	1/	26,306.4	North Fork Shenandoah
Licking Creek	13	120,500	1/	18,086.6	Licking Creek
Mount Storm	14	43,500	4,500	15,623.5	Stony
Seneca	15	1,193,000	460,000	187,091.1	Potomac
West Branch	16	77,500	1/	18,629.1	West Branch Conocheaque
Winchester	17	77,000	1/	17,571.2	Opequon Creek

1/ No flood control storage is included in these projects, but there are flood damage reduction benefits.

PROJECTED FLOOD DAMAGE

AREA 19

Potomac River Basin

Emphasized Objective: EQ

PROJECTED FLOOD DAMAGE

AREA 19

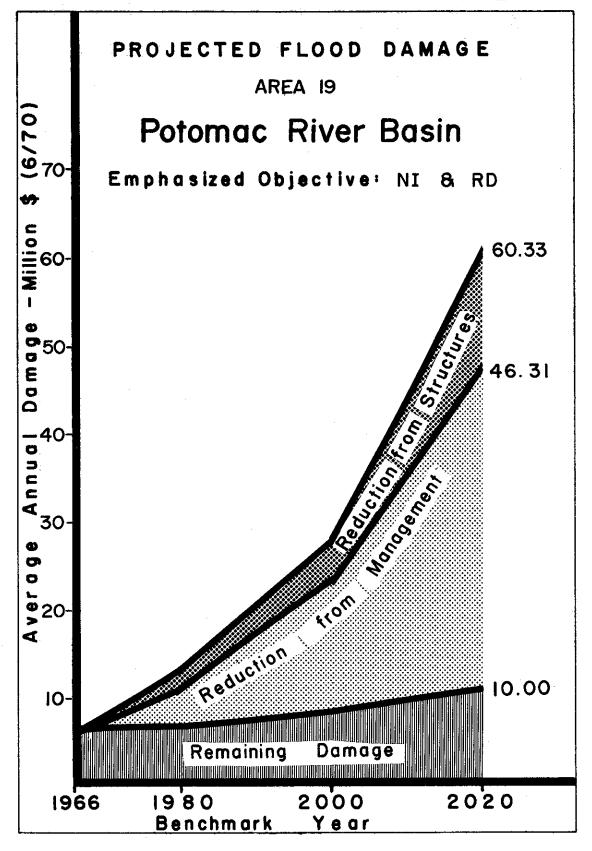# Potomac River Basin

Emphasized Objective: NI & RD

FIGURE E-62

AREA 20 RAPPAHANNOCK AND YORK RIVER BASINS

AREA 20. RAPPAHANNOCK AND YORK RIVER BASINS

Area 20 includes the Rappahannock River Basin, Sub-area 20a, and the York River Basin, Sub-area 20b, and has a combined total drainage area of 6,000 square miles. Sub-area 20a contains about 45% of the total. The area has no existing major storage development.

FLOOD DAMAGE REDUCTION

Area 20 flood damages include the main stem drainage of the Rappahannock and York Rivers, coastal drainage to Chesapeake Bay, and tidal flooding. Negligible amounts of damage occur in the York Basin. Average annual flood damages in the Rappahannock and Chesapeake Bay and tributaries are distributed, under 1966 conditions, as follows: Rappahannock River - 39%, and Chesapeake Bay - 61%.

Present and projected damages in this Area are among the lowest in the North Atlantic Region. Flooding is not considered a major problem in the Area, although record floods on the Rappahannock have occurred at about 80 times the average streamflow. The flood of record in the Rappahannock Basin occurred on October 13 and 14, 1942, causing an estimated $2.3 million in damages. If this flood were to recur under 1966 conditions, it would cause estimated damages of about $14.4 million (June 1970 prices). The low degree of development in the flood plain is the main reason for low damages.

No differences are visualized between objectives in Area 20. Construction of the proposed Salem Church multi-purpose, hydroelectric project is assumed by 2000, and a slightly higher than average effectiveness factor, 45%, is considered likely.

The status of Federal flood damage reduction projects in Area 20 is shown in Table E-29.

TABLE E-29
STATUS OF FLOOD DAMAGE REDUCTION PROJECTS - AREA 20

FLOOD STORAGE PROJECTS
(Map Symbol ▣)

AUTHORIZED (See Figure E-68)

Project	Map Number	Total Storage (Acre-feet)	Flood Control Storage (Acre-feet)	Estimated Total Cost ($1,000)	Year Authorized	River
Salem-Church	14	1,048,000	256,000	94,900.0	1968	Rappahannock

WATER MANAGEMENT

Average annual runoff in Area 20 is approximately 3,680 m.g.d. The existing minimum monthly flow (shortage index 0.01) is 130 m.g.d., and the corresponding seven-day minimum is about 50% of this total, or 65 m.g.d. (See Appendix C). The addition of 13 m.g.d. as an allowance for consumptive losses, results in an existing firm resource available for use of 78 m.g.d., or 2% of the average runoff.

The practical limit of development within the Area, based on potential yield of new surface storage and additional ground water, would provide a maximum available resource of 1,702 m.g.d., or 46% of the average runoff. Potential sources which would develop the increase of 1,624 m.g.d., include major storage, accounting for 52% of the increase; upstream storage, 32%, and ground water development, 16%.
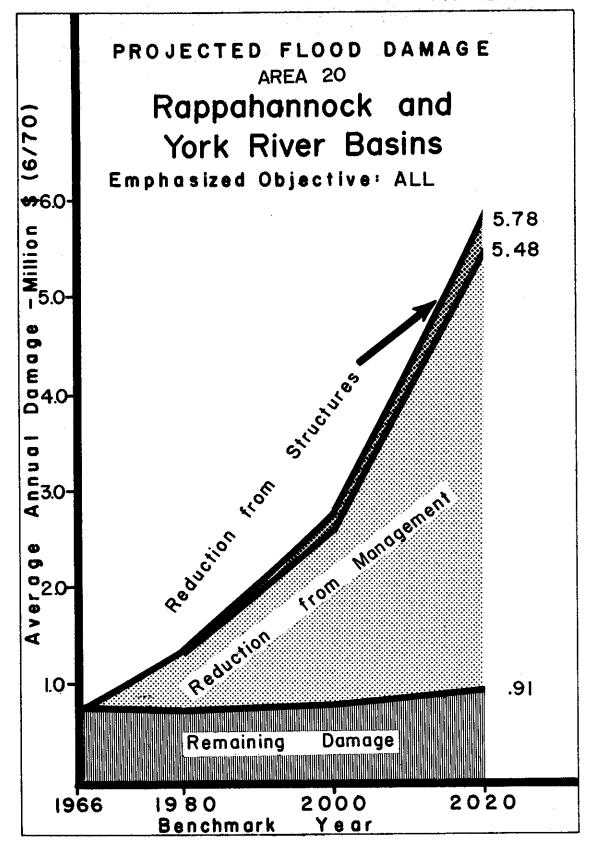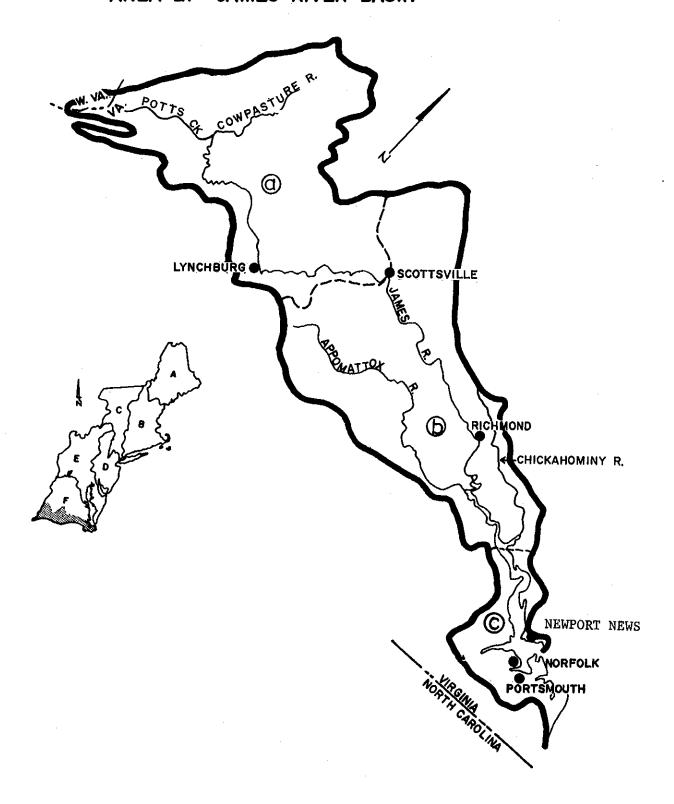
PROJECTED FLOOD DAMAGE
AREA 20
**Rappahannock and
York River Basins**
Emphasized Objective: ALL

FIGURE E-64

AREA 21   JAMES RIVER BASIN

AREA 21. JAMES RIVER BASIN

The James River Basin, draining parts of West Virginia and Virginia, has a total drainage area of 10,600 square miles. Sub-area 21a, above Scottsville, Va., contains about 43% of the drainage area; Sub-area 21b, the local area between Scottsville and the confluence of the James and the Chickahominy Rivers, contains about 47%; and 21c contains the remainder.

There are nearly 18,000 acre-feet of existing storage in the Area, used for municipal supply. Gathright Lake, which is under construction in Sub-area 21a, will add about 204,000 acre-feet of usable storage for flood control, water quality, and recreation purposes.

FLOOD DAMAGE REDUCTION

Area 21 flood damages include both fluvial and tidal flooding and average annual damages, under January 1966 conditions, are distributed as follows: James River and Tributaries - 64%, and Tidal and Coastal - 36%.

Authorized projects would reduce damages by 9% under January 1966 conditions. Flooding is a major problem in the Area. Major floods of record have been about 30 times the average streamflow on the James, with ratios commonly double that in the headwaters and along the major tributaries. The flood of record occurred on March 16-18, 1936, and caused damages estimated at $2.9 million. If this flood were to recur under January 1966 conditions, it would cause damages estimated at $32.4 million, in June 1970 prices.

Differences between objectives are substantial in the James Basin. Under the Environmental Quality objective, scenic values have dictated sole reliance on flood plain management measures. Regional Development and National Efficiency objectives will require a combination of structural and non-structural devices. Flood plain management techniques are considered to have an average chance of effectiveness in Area 21, and an effectiveness factor of 35% was used for all objectives.

The Regional Development and National Income objectives, in addition to flood plain management, assume the operational capability of several projects in future bench mark years, as follows: 1980 -- Gathright Lake; 2000 -- the Hipes, Buffalo No. 3, Stonehouse and Upper Cartersville reservoirs, and local flood protection at Richmond, Buena Vista and Virginia Beach.

The status of Federal flood damage reduction projects in Area 21 is shown in Table E-30.

TABLE E-30
STATUS OF FLOOD DAMAGE REDUCTION PROJECTS – AREA 21

LOCAL PROTECTION PROJECTS
(Map Symbol ▲)

EXISTING (See Figure E-67)

Project	Map Number	Total Cost ($1,000)	Year Completed	River
Newmarket	92	1,550.1	1969	Newmarket Creek
Norfolk	93	2,626.0	1971	Elizabeth

UNDER CONSIDERATION (See Figure E-68)

Project	Map Number	Estimated Total Cost ($1,000)	River
Buena Vista	43	9,360.0	Maury
Richmond	44	5,090.0	James
Virginia Beach	45	18,150.0	Atlantic Ocean

FLOOD STORAGE PROJECTS
(Map Symbol ▢)
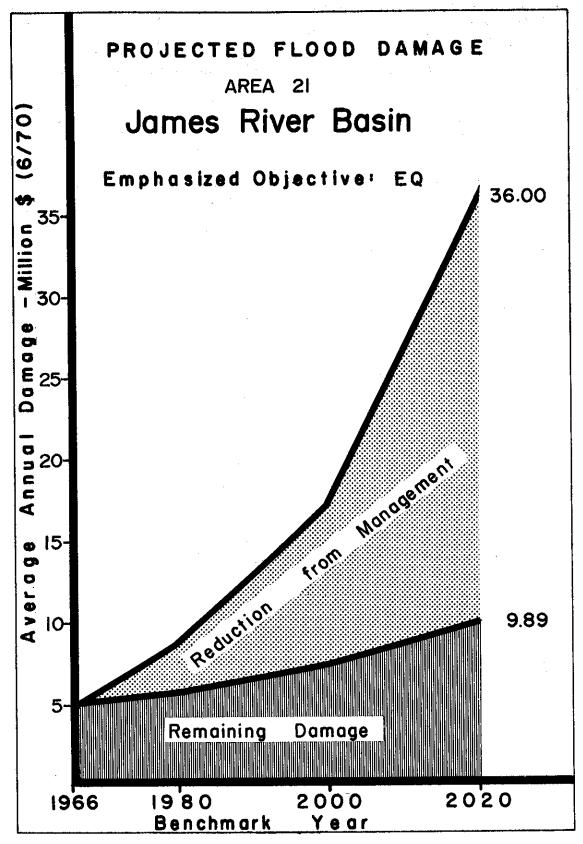
AUTHORIZED (See Figure E-68)

Project	Map Number	Total Storage (Acre-feet)	Flood Control Storage (Acre-feet)	Estimated Total Cost ($1,000)	Year Authorized	River
Gathright (UC)	29	204,000	80,000	33,960.0	1946	Jackson

UNDER CONSIDERATION (See Figure E-68)

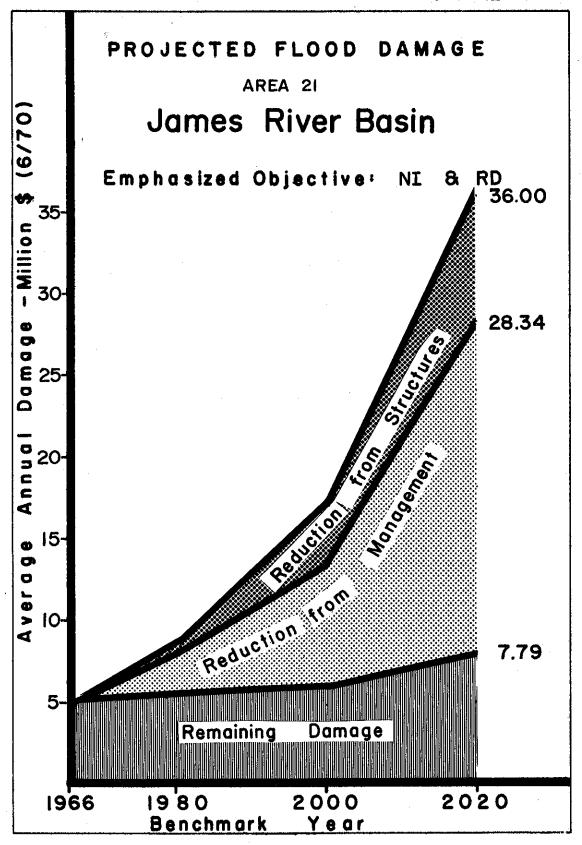| Project	Map Number	Total Storage (Acre-feet)	Flood Control Storage (Acre-feet)	Estimated Total Cost ($1,000)	River
Buffalo No. 3	18	350,000	87,000	26,900.0	Tye
Hipes	19	298,000	73,000	29,745.0	Craig Creek
Stonehouse	20	220,000	23,000	24,400.0	Catawba Creek
Upper Cartersville	21	422,000	56,000	31,400.0	Willis

UC - Under Construction

WATER MANAGEMENT

Area 21's average annual runoff is approximately 7,450 m.g.d.
The existing minimum monthly flow (shortage index 0.01) is 880 m.g.d.,
and the corresponding seven-day minimum is about 55% of this total, or
480 m.g.d. (See Appendix C). Allowance for yield from Gathright Lake
raises the latter value to about 597 m.g.d. The addition of 77 m.g.d.
for consumptive losses, results in a firm resource available for use
of about 674 m.g.d., or 9% of the average runoff.

The practical limit of development within the Area, based on
potential yield of new surface storage and additional ground water,
would provide a maximum available resource of 2,938 m.g.d., or 39% of
the average runoff. Potential sources which would develop the increase
of 2,264 m.g.d., include major storage, accounting for 34% of the in-
crease; upstream storage, 41%, and ground water development, 25%.

FIGURE E-65

PROJECTED FLOOD DAMAGE

AREA 21

James River Basin

Emphasized Objective: EQ

PROJECTED FLOOD DAMAGE

AREA 21

James River Basin

Emphasized Objective: NI & RD

FIGURE E-67

NAR PROJECT MAP

EXISTING PROJECTS

(In pocket in back of book)

FIGURE E-68

NAR PROJECT MAP

POTENTIAL PROJECTS

(In pocket in back of book)

FIGURE E-67
EXISTING PROJECTS
NORTH ATLANTIC REGION

NORTH ATLANTIC REGIONAL
WATER RESOURCES STUDY

Appendix E
Flood Damage Reduction
and Water Management
for Major Rivers
and Coastal Areas

LEGEND
▲ LOCAL PROTECTION — EXISTING
■ FLOOD STORAGE — EXISTING

LEGEND

▲	LOCAL PROTECTION	— AUTHORIZED
■	FLOOD STORAGE	— AUTHORIZED
▲	LOCAL PROTECTION	— INACTIVE
■	FLOOD STORAGE	— INACTIVE
▲	LOCAL PROTECTION	— UNDER CONSIDERATION
■	FLOOD STORAGE	— UNDER CONSIDERATION

FIGURE E-68
POTENTIAL PROJECTS
NORTH ATLANTIC REGION

NORTH ATLANTIC REGIONAL
WATER RESOURCES STUDY

Appendix E

**Flood Damage Reduction
and Water Management
for Major Rivers
and Coastal Areas**

10   0   10   20   30   40 Miles
SCALE